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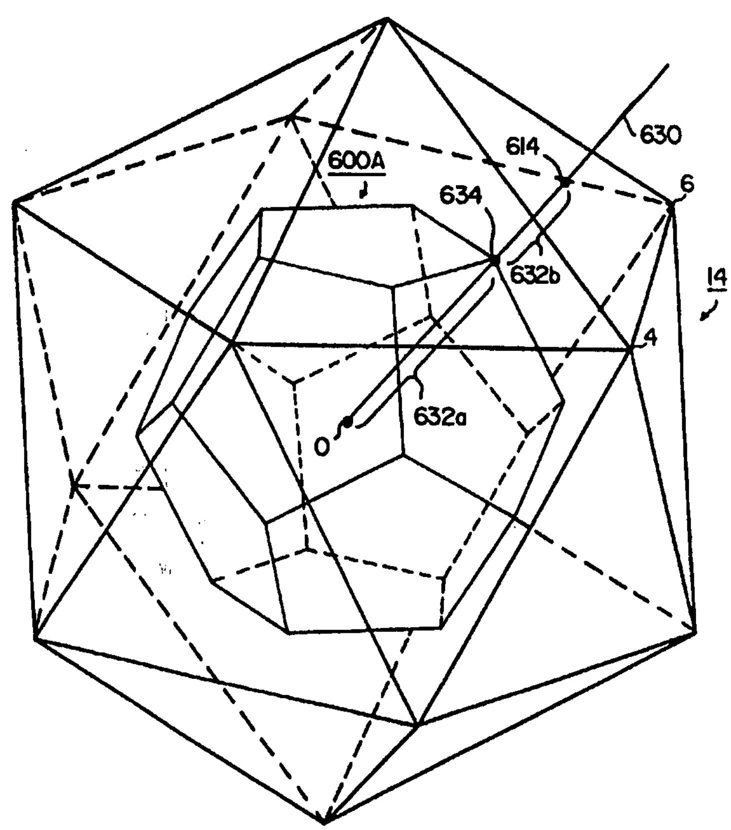
(57) Abstract

Each of the acoustic transducers (elements) of an array has a maximum dimension of less than λ. They are located at the vertices (4, 6) of a regular polyhedron (14), which may be an icosahedron (12 elements), or a dodecahedron (20 elements). This placement effectively locates the elements on the surface of a sphere with diameter selected to provide an interelement spacing of $\lambda/3$ to $2\lambda/3$. The signals are delayed for phasing to form directive "beams". A second array includes elements located at the vertices (6, 34) of a smaller polyhedron (600A) centered at the same point and included within the first array, and operated at a higher frequency than the outermost array. In order to reduce the effects of shadowing, the locations of the transducers of the smaller included array (600A) are selected to lie on radials (630) passing through the centroids (614) of the faces of the polygon defining the larger array (14).



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POLYHEDRAL DIRECTIONAL TRANSDUCER ARRAY

FIELD OF THE INVENTION

This invention relates to transducer arrays, and more particularly to polyhedral arrays of acoustic transducers such as those used for sonar and underwater detection, location or monitoring.

BACKGROUND OF THE INVENTION

Acoustic transducers are used for transducing acoustic (sound) energy with electrical energy. This may be useful, for example, for producing sound in response to electrical signals, as in a loudspeaker, or for producing electrical signals in response to sound energy, as in a microphone. In this context, the term sound also means ultrasound. The design of an acoustic transducer is strongly impacted by the fluid medium for which it is intended, and whether it is intended for producing sound energy in the medium, or extracting energy therefrom. When electrical energy is applied to the acoustic transducer for coupling to the fluid medium, the transducer must be strongly coupled to the fluid, otherwise the electrical energy will not be transferred to the fluid (will be reflected to or remain in the electrical source), or will be absorbed in the transducer itself, thereby causing heating. Strong coupling to the medium generally means a relatively large aperture, so that significant amounts of the fluid may be moved in response to the electrical energy, and the structure must be sufficiently large to handle the heat energy and forces involved in the transduction. Acoustic transducers intended for sensing or picking up sounds, on the other hand, may be small, as they are unlikely to absorb so much energy from the medium that they heat up, and the relatively small electrical signals which are produced can generally be amplified to useful levels. A further advantage of physically small transducers is that they tend to have relatively good frequency response, by

comparison with larger transducers, because their mechanical resonances occur at higher frequencies than those of larger transducers, and they therefore have a broader frequency range over which the amplitude response of the transducer is flat.

Transducers for underwater purposes such as sonar are often operated in both a transmission mode, and, at a different time, in a reception mode. The requirements of the transmission mode tend to dominate the design of such transducers. U.S. Patent 5,239,518, issued August 24, 1993 in the name of Kazmar, describes one such sonar transducer, therein termed a "projector." The Kazmar transducer includes an electrostrictive or piezoelectric material, which responds to electrical signals to produce corresponding acoustic signals, and which also transduces in the other direction, producing electrical signals in response to acoustic energy.

The velocity of sound signals depends upon the density of the medium; the velocity of sound in air is about 1100 ft/sec., in water about 4800 ft/sec., and in steel about 16000 ft/sec. Since the wavelength in a medium at a given frequency is directly related to the velocity of propagation, the wavelength in water at any given frequency is much larger than in air. Consequently, a given structure is smaller, in terms of wavelengths, in water than in air. Therefore, structures such as acoustic transducers tend to be relatively small in terms of wavelength when immersed in their fluid medium, water. A concomitant of small size in terms of wavelength is isotropy or nondirectionality of the response; a transducer which is very small in terms of wavelengths effectively appears to be a point source, and transduces in a nondirectional or omnidirectional manner.

Directional transduction is desirable for many reasons. For example, when using a transducer to listen to distant sound sources, a directional "beam" tends to reduce the influence of noise originating from other

directions. When transmitting acoustic energy toward the location of an object to be detected by observation of the acoustic reflection, a directional transmission "beam" concentrates the available energy toward the object, making it more likely that sufficient energy strikes the object that its reflection can be detected. However, as mentioned, an acoustic transducer tends to be small in terms of wavelength, and to provide omnidirectional transduction.

A well-known method for increasing acoustic directionality is to arrange a plurality of individual transducers in an array. For example, long "line" arrays of acoustic transducers may be spaced along a cable, and towed behind a ship performing undersea examination. The acoustic transducers are energized simultaneously in a transmit mode, so that they act in concert, with the result that the effective dimension of the transmitting transducer is established by the length of the cable, rather than the dimension of an individual transducer. This enables a directional beam to be produced, which in the case of the described towed array is a "fan" beam orthogonal to the cable's length. The same towed array, operated as a receive transducer, combines all of the received signals without relative delays or phase shifts, and achieves a "receive beam" corresponding to the abovementioned fan beam.

Other types of arrays are known. An April, 1987 report prepared for Naval Underwater Systems Center, New London, CT, under contract NICRAD-85-NUSC-022 describes an array of twenty-one transducers in the form of a right circular cylinder, which is advantageous because of its symmetry in the horizontal plane, and the resulting 360-degree azimuth coverage. The diameter and height of the described cylindrical array are about one wavelength. The elements were driven with relative time delays for phasing to a plane.

Improved array configurations are desirable.

SUMMARY OF THE INVENTION

A transducer array according to the invention includes a plurality of acoustic transducers for use in a fluid medium. Each of the transducers has a maximum dimension of less than one acoustic wavelength in the medium. The acoustic transducers are arrayed with their acoustic centers at the vertices of a regular polyhedron defining vertices and more than six sides. In one embodiment of the invention, the polyhedron is an icosahedron, and the number of transducers or array elements is twelve. In another embodiment, the polyhedron is a dodecahedron, and there are twenty transducers. Placement at the vertices of a regular polyhedron effectively places the elements of the array in a regular manner on the surface of a sphere, with the inter-element spacing not necessarily equidistant. The transducers are physically arrayed by a support structure, and electrically arrayed by at least one of a transmitter or drive arrangement, which may be associated with the array as a whole, or with individual units for each transducer, for generating electrical analogues of the desired acoustic signal, and by a receiver for receiving transduced signals from the transducers. Such a structure, because of its uniformity in three dimensions, can provide a particularly uniform omnidirectional or isotropic response, at least over a limited frequency range. A particularly desirable arrangement includes delays for phasing the signals to form transmission or reception "beams" having directivity. Arrays with a diameter providing an interelement spacing of about one-third to two-thirds of a wavelength have been found to provide good characteristics over an octave frequency bandwidth. Such a sphere diameter for an icosahedron is about 1.903 times the interelement spacing. According to a further aspect of the invention, a second array is associated with the first array, with the elements of the second array being located at the vertices of another

polyhedron different from the first polyhedron, with both polyhedra centered at the same location. In one embodiment, the first array includes elements located on at least some, and preferably all, of the twelve vertices of an icosahedron, and the second array includes elements located on at least some, and preferably all, of the twenty vertices of a dodecahedron. The dodecahedron's twenty vertices are coradial (lie on the same radial) with the centroids of the twenty faces of the icosahedron. In other words, each of the vertices of the dodecahedron lies on one of the radials which passes through the centroid of one of the twenty faces of the icosahedron. The interelement spacing along the perimeter chords of the pentagonal face of the dodecahedron is (approximately) 50% of the interelement spacing along one chord of the isosceles triangular face of the icosahedron. The second array is provided with its own transmitter(s) andor receiver, and controlled delays, if desired, for creating a directional beam, which may be coincident with the icosahedral array beam.

DESCRIPTION OF THE DRAWING

FIGURE 1 is a perspective or isometric view of a geometric solid icosahedron;

FIGURE 2a is a simplified perspective or isometric view of an acoustic transducer, and FIGURE 2b is a side elevation view of two such transducers and a portion of a support structure which supports the transducers at the vertices of the icosahedron of FIGURE 1;

FIGURE 3 is a simplified perspective or isometric view of the support structure for an icosahedral array;

FIGURE 4 represents the transducers located by the support structure of FIGURE 3;

FIGURE 5 is a simplified block diagram of an array, showing transmitter and receiver;

FIGURE 6a represents an icosahedron with twenty faces, and the vertices of a smaller included concentric

dodecahedron located on radials extending from the center through the centroids of the faces of the icosahedron, and FIGURE 6b represents an icosahedral array with an included dodecahedral array;

FIGURE 7a is a plot illustrating considerations which relate wavefront delays and propagation direction of a directional beam from an array, FIGURE 7b is an illustration of a three-dimensional coordinate system for enhanced understanding of radiation plots;

FIGURES 8a-8i are plots of the response of an array of FIGURE 6a, in a vertical plane passing through ϕ_s, at different frequencies, and FIGURES 9a-9i are plots of the response of the same array at the same frequencies, but in a horizontal plane; and

FIGURE 10a is a plot of the response of an inner array of a pair of nested arrays as in FIGURE 6b, and FIGURE 10b is a plot of the response of the outer array.

DESCRIPTION OF THE INVENTION

FIGURE 1 illustrates a conceptual geometric solid icosahedron 14, including twelve vertices designated by numerals 1-12, where the hyphen represents the word "through." The illustrated vertices of the icosahedron in one embodiment of the invention are located at X, Y and Z coordinates, measured in inches, as listed in Table I:

TABLE I

VERTEX	X	Y	Z
1	0	0	5.654
2	-5.057	0	2.529
3	-1.563	4.810	2.529
4	-1.563	-4.810	2.529
5	4.091	2.973	2.529
6	4.091	-2.973	2.529
7	-4.091	2.973	-2.529
8	-4.091	-2.973	-2.529
9	1.563	4.810	-2.529
10	1.563	-4.810	-2.529
11	5.057	0	-2.529
12	0	0	-5.654

The vertices of icosahedron 14 together define twenty faces, each of which may be identified by the designations of the three vertices by which it is defined. The vertices of icosahedron 14 lie at equal radii from the origin of the coordinate system. According to an aspect of the invention, acoustic transducers are physically located with their acoustic centers at the vertices of the icosahedron 14. Each acoustic transducer may be of the magnetically actuated, piezoelectric, electrostrictive, or any other type, as known in the art. Placement of the transducers on the surface of a sphere allows the array to perform in an omnidirectional or isotropic manner, by comparison with line, flat or cylindrical arrays. In order to enhance omnidirectionality, each acoustic transducer is limited in size, with its maximum or largest dimension being limited to less than one wavelength of the medium at the highest frequency of interest. In a transmission mode, the highest frequency of interest corresponds to the highest transmitted frequency.

FIGURE 2a is a simplified perspective or isometric view of one form of acoustic transducer 210 which may be used in the array of FIGURE 1. In FIGURE 2a, the transducer has flat, mutually parallel upper and lower

faces 212 and 214, respectively, which are provided for support, and the active portions of the transducer occupy the oblate or elliptical right cylindrical body 216 lying between the upper and lower support faces. An axis 208 passes through acoustic center 206 of transducer 210. Axis 208 is parallel to the Z axis of FIGURE 1. If axis 208 of FIGURE 2a were coincident with the Z axis of FIGURE 1, transducer 210 of FIGURE 2a would thereby be identified as corresponding to the transducer located at either vertex 1 or 12 of FIGURE 1. FIGURE 2b is a side elevation view of two acoustic transducers such as 210 of FIGURE 2a, namely transducers 210(1) and 210(4), where the parenthetical designation identifies the vertex of the polyhedron or array of FIGURE 1 upon which the particular transducer is centered. FIGURE 2b also shows a central support shaft 230 extending parallel to or coincident with the Z axis of FIGURE 1, and a support yoke 232 supported by a coupling ring 234 on central support shaft 230. Support yoke 232 includes an upper leg 236 fastened by a screw 238 to upper face 212 of transducer 210(4), and a lower leg 240 fastened by screws 242 and 244 to its lower face 214. A pair of electrodes 246a and 246b are provided for making electrical contact with the internal active portions of transducer 210(4). Also in FIGURE 2b, transducer 210(1), which corresponds with the uppermost transducer in the array of FIGURE 1, has its lower support plate 214 fastened to a plate 251 by screws 252 and 254, and is not supported at its upper plate 212. Transducer 210(1) of FIGURE 2b is also provided with electrical contacts designated 256a and 256b.

FIGURE 3 is a perspective or isometric view of the entirety of the support structure of FIGURE 2b. In FIGURE 3, elements corresponding to those of FIGURE 2b are designated by like reference numerals. In FIGURE 3, support shaft 230 is seen to support a lower support ring 334 and a lower support plate 351 in addition to upper support ring 234 and upper support plate 251. Each

support ring supports five yokes such as yoke 232, equally spaced at 72° increments. Support rings 234 and 334 are mutually offset by 36°, so that the acoustic centers of the transducers to be supported lie at the correct locations as identified by vertices 1-12 of the polyhedron of FIGURE 1. FIGURE 4 is a computer-generated representation of a complete set of transducers similar to those of FIGURES 2a and 2b, in the locations in which the support of FIGURE 3 places them, and formed into an array 400.

Instead of the support of FIGURE 3, the physical structure which supports the array of transducers may be a system of struts which parallels or coincides with the lines which extend from vertex to vertex to define the faces of the polyhedron, such as line 16, extending between vertices 2 and 3 of FIGURE 1. A physical support structure such as that described in conjunction with FIGURE 1 may be costly, in that it may require connections to each transducer from five different directions, and the structure of FIGURE 3 is preferred.

FIGURE 5 is a simplified block diagram of a transmitter and receiver system using the transducer array of FIGURE 4. In FIGURE 5, the transmitter includes a source of electrical signals at one or more frequencies, or at varying frequencies, which is coupled to a signal divider (also known as a power divider) 512, which divides the signal into twelve portions (for use with the icosahedral array), and which applies each of the signal portions to a controlled delay (D) element 514, namely delay elements 514a, 514b, ... , 514c, for delay of the signal in accordance with array constants and the desired beam pattern. The delayed signals from each delay element are applied to the input of a corresponding power amplifier 516. More specifically, the delayed output signal from delay element 514a is applied to amplifier 516a for amplification therein, the delayed output signal from delay element 514b is applied to amplifier 516b for

amplification therein, ..., and the delayed output signal from delay element 514c is applied to amplifier 516c for amplification therein. The amplified signals from amplifiers 516 each are applied by way of one of switches 518, in the illustrated positions thereof, to one of transducers 210. Thus, the amplified output from amplifier 516a is applied by way of switch 518a to transducer 210(1), the amplified output from amplifier 516b is applied by way of switch 518b to transducer 210(2), ..., and the amplified output from amplifier 516c is applied by way of switch 518c to transducer 210(12). When source 510 of FIGURE 5 is energized with switches 518 in their illustrated positions, amplified, selectively delayed electrical signals are applied to the transducers, and acoustic signals are radiated into the medium in a direction, and with sidelobe characteristics, established by the array dimensions, the velocity of propagation in the fluid medium, and the relative delays.

In an actual embodiment of the array used for experimental purposes, source 510 of FIGURE 5 was a personal computer producing digital equivalents of sinusoidal signals, and the power divider 512/delay 514 combination was provided by a multichannel digital-to-analog converter (DAC) arrangement.

For reception of signals by transducers 210 of FIGURE 5, switches 518 are thrown to their alternate positions, not illustrated in FIGURE 5, thereby decoupling each transducer 210 from its associated power amplifier 516, and coupling the transducer instead to a receiver illustrated as a block 524. Block 524 may include delays corresponding to delays 514, with corresponding delay values or with different delay values, for forming a receive beam as generally known in the art. The receiver may also process the signals for extracting information therefrom, as for example determining the delay time between transmission of a signal and its reflection, for

determining the distance to the reflecting object or medium condition.

FIGURE 6a is a perspective or isometric view similar to FIGURE 1, illustrating vertices 1-12 of icosahedron 14, with connecting lines to provide dimensional cues. As mentioned, an icosahedron has twelve vertices defining twenty faces, not all of which are visible in FIGURE 6a. A dodecahedron has twenty vertices defining twelve faces. In FIGURE 6a, icosahedron 14 of FIGURE 1 is centered on the origin O of the coordinate system, and includes a smaller dodecahedron designated generally as 600, also centered on the origin O of the coordinate system, none of which is visible.

As an aid in visualizing the position of the included dodecahedron, the centroids of the faces of the icosahedron are illustrated in FIGURE 6a. More specifically, using the face identification convention previously stated, point 611 represents a centroid of face 1,3,5 of icosahedron 14; a second point 612 represents the centroid of face 1,2,3 of icosahedron 14; a third point 613 represents the centroid of face 1,2,4; a fourth point 614 represents the centroid of face 1,4,6; a fifth point 615 represents the centroid of face 1,5,6; a sixth point 616 represents the centroid of face 2,3,7; a seventh point 617 represents the centroid of face 2,7,8; an eighth point 618 represents the centroid of face 2,4,8; a ninth point 619 represents the centroid of face 4,8,10; and a tenth visible point 620 represents the centroid of face 4,6,10 of icosahedron 14. Other centroids lie in other faces of icosahedron 14 which are not visible in FIGURE 6a. In FIGURE 6a, a line 630 represents a radius extending from the origin O of the coordinate system through centroid 614 of face 1,4,6. Corresponding radii may be considered to extend from origin O through each of the other centroids of the faces of icosahedron 14, but are not illustrated to avoid complicating FIGURE 6a. That portion of radius 630 lying within icosahedron 14, namely that portion of line

630 extending from origin O to centroid 614, may be considered to be divided at a point 614 into two portions 632a and 632b. The lengths of line portions 632a and 632b may be equal. Dividing point 634 is the location of one of the twenty vertices of the included dodecahedron 600. Similarly, each of the corresponding points on each of the twenty other radii (not illustrated) which extend from origin O to the centroids 611-613 and 615-620 of the other faces of icosahedron 14 is the location of one of the twenty other vertices of included dodecahedron 600. Thus, the included dodecahedron has a diameter of about half of that of the icosahedron.

According to an aspect of the invention, a second array of transducers, similar to array 400 of FIGURE 4 except for the number of transducers arrayed, has its elements located at the vertices of dodecahedron 600 of FIGURE 6a, interspersed among the elements of the icosahedral array 400 of transducer elements. Since the second array coincides with the vertices of dodecahedron 600 of FIGURE 6a, the second array is designated 600A of FIGURE 6b. Each transducer of second array in transducers 600A is connected with other elements thereof, and with a source, controllable delays, amplifiers, switches, receivers similar to those described in conjunction with FIGURE 5, the sole difference being the frequency or the frequency range of the second source. Thus, an icosahedral array, associated with its own transmitter and receiver, can occupy the same volume as a dodecahedral array, operating at a different frequency range and associated with at least a different receiver.

It should be noted that a computer model was made of a pair of nested icosahedral arrays similar to that described above, but with the transducers of both icosahedral arrays on the same radial. The model indicated that shadowing of the transducers of one array was produced by the transducers of the other array, and

the results were inferior to the results using the nested icosahedral-dodecahedral arrays.

Dodecahedral array 600A, located inside the icosahedral array of FIGURE 6b, has twenty transducer elements, instead of twelve. The dodecahedral array is made with transducer elements (not illustrated) which are smaller than the transducer elements, illustrated in FIGURE 4, of the icosahedral array. Since each transducer element of the dodecahedral array is smaller than a transducer element of the icosahedral array, its effective aperture is smaller. When operated at a higher frequency than the transducers of the icosahedral array, the transducers of the dodecahedral array have roughly the same dimensions in wavelengths, so they also tend to be omnidirectional. However, the smaller physical dimensions of the transducers of the dodecahedral array relative to the transducers of the icosahedral array means that the smaller transducers can accept less electrical energization power before cavitation effects begin to occur in a water medium. Thus, the peak output power of a transducer of the dodecahedral array is more limited than the peak output power of a transducer of the icosahedral array. The peak acoustic power which the dodecahedral array can transmit, however, is about equal to that of the icosahedral array, because the dodecahedral array has twenty transducers, while the icosahedral array has only twelve transducers.

In a preferred embodiment of the invention, the icosahedral array covers an octave range, while the included dodecahedral array covers the next higher adjacent octave, thereby providing a two-octave range. In the middle of its octave range, the inter-element spacing of each array is about $\lambda/2$, but good operation occurs in the range of about $\lambda/3$ to $2\lambda/3$.

One of the advantages of the polygonal array according to the invention is that the beam can be steered in three dimensions. FIGURE 7a illustrates considerations

determining the amount of delay required in the delays 514 of FIGURE 5 to steer the beam in a given direction. In FIGURE 7a, the center of the array is O, and dotted line 710 illustrates the desired beam direction. A number of straight lines 712 and 714a, 714b, 714c, 714d, are drawn perpendicular (90°) to line 710, with line 712 passing through the center O of the array, and with each line 714 passing through the projection, into the plane of the FIGURE, of the location of the acoustic center of one of the transducers of the array. Each line 714 may be viewed as representing a plane wavefront propagating in the direction of line 710, and line 712 may be viewed as a reference wavefront occurring at a reference time. In FIGURE 7a, points 716a, 716b, 716c, and 716d represent the projections into the plane of the FIGURE of some of the transducers of the array. Points 716a, 716b, 716c, and 716d are associated with wavefronts 714a, 714b, 714c, and 714d, respectively. Also indicated in FIGURE 7a are distances d_1 and d_2, which represent the distance between wavefront 716b and reference wavefront 712, and between wavefront 716c and reference wavefront 712, respectively. A corresponding distance exists between the projection of each transducer of the array and the reference wavefront. The value of this distance will, in general, be different for each wavefront so constructed. In order to cause propagation in the direction of line 710 of FIGURE 7a, the timing of wavefronts 714a and 714b must be earlier than, or lead reference wavefront 712, while the timing of wavefronts 714c and 714d must be later or lagging. This timing difference, whether positive or negative, is generally termed a "delay." The magnitude of the time delay t associated with each wavefront relative to the reference wavefront is the physical distance or dimension (d_1 or d_2) therebetween, divided by C, the velocity of propagation of the acoustic energy in the fluid medium

$$t = d/C$$

FIGURE 7b illustrates a three-dimensional coordinate system defining the direction of line of propagation 710 of FIGURE 7a in terms of azimuthal angle ϕ_s and zenith angle θ_s.

As an example, for the icosahedral array of FIGURE 1 with the dimensions indicated in TABLE I, steering in direction $\phi_s = 30°$, $\theta_s = 120°$, the delays required in the channels corresponding to delay elements 514 of FIGURE 5 are

TABLE II

ELEMENT #	DELAY* (MICROSECONDS)
1	-47.11
2	-84.29
3	-75.33
4	- 5.90
5	+ 8.61
6	+51.52
7	-51.52
8	- 8.61
9	+ 5.90
10	+75.33
11	+84.29
12	+47.72

where the minus sign (-) represents a negative delay relative to the reference wavefront.

FIGURES 8a, 8b, 8c, 8d, 8e, 8f, 8g, 8h, and 8i are computer modeled plots in dB of the dodecahedral transducer array pattern at $\phi = \phi_s$ (a "vertical" pattern) at 2750, 3250, 3750, 4250, 4750, 5250, 5750, 6250, and 6750 Hz, respectively, with the delays set for generating a beam at $\phi_s = 0°$, $\theta_s = 90°$, in the absence of a surrounding icosahedral array. The "S" subscripts associated with ϕ_s and θ_s represent fixed steering angles. The dash-line circle on each plot represents 3 dB below the main beam peak amplitude. The frequency corresponding to the center of the octave band is 4750 Hz., at which

frequency the interelement spacing, as described above, is approximately $\lambda/2$. The directional beam peak at $\theta = 90°$ is clear. Similarly, FIGURES 9a, 9b, 9c, 9d, 9e, 9f, 9g, 9h, and 9i are plots in dB of the dodecahedral transducer array pattern at $\theta = \theta_s$ (a "horizontal" pattern) at 2750, 3250, 3750, 4250, 4750, 5250, 5750, 6250, and 6750 Hz, respectively, with the delays set for generating a beam at $\phi_s = 0°$, $\theta_s = 90°$. The beam peaks at $\phi = 0°$ are clear.

Computer model plots of a nested array system similar to that of FIGURE 6b were made. FIGURE 10a is a "vertical" plot at $\theta = 0°$, which represents the beam formed by the inner dodecahedral array at 3750 Hz, with phasing set to produce a beam at $\phi_s = 0°$, $\theta_s = 90°$, in the presence of an unpowered icosahedral surrounding array. FIGURE 10a may be compared with FIGURE 8c, which has no surrounding array. While details of the sidelobe pattern are different, the main beams are similar. FIGURE 10b is a "vertical" plot of $\theta = 0°$, which represents the beam formed by the outer icosahedral array near midband at 2500 Hz, with phasing set to produce a beam at $\phi_s = 0°$, $\theta_s = 90°$, in the presence of an unpowered included dodecahedral array.

Other embodiments of the invention will be apparent to those skilled in the art. For example, delays 514 of FIGURE 5 may follow their respective power amplifiers 516 in the signal path, or they may be located between each switch 518 and the associated transponder 210, which is particularly advantageous, because the same delay can then be used for both transmission and reception to for similar beam patterns. While the two interspersed arrays can have completely different transmitters and receivers, a common receiver and display may be used, and switched between the arrays, since an operator may only be able to give attention to one display at a time. While two nested or interspersed arrays are described, other geometric figures may be chosen, and dimensions selected, to allow nesting of three or more transducer arrays. Also, the dodecahedral

array may have its elements located at the centroid of the faces of the icosahedral array, or the dodecahedral array might even have a greater diameter than the icosahedral array with which it is nested, because the shadowing caused by the outermost elements would be minimal, as a result of the small subtended angle of the transducers of the outermost array as seen from the inner array.

CLAIMS

1. A transducer array, comprising;

a plurality of acoustic transducers for use in a fluid medium, each of said transducers having maximum lateral dimensions less than one acoustic wavelength in said medium; and

arraying means for arraying said acoustic transducers at the vertices of a regular polyhedron defining vertices and more than six sides.

2. An array according to claim 1, wherein said polyhedron is an icosahedron, and said plurality equals twelve.

3. An array according to claim 1, wherein said polyhedron is a dodecahedron, and said plurality equals twenty.

4. An array according to claim 1, wherein the diameter of said polyhedral array is selected to provide an interelement spacing in the range of 1/3 to 2/3 wavelength.

5. An array according to claim 1, wherein the largest dimension of any one of said acoustic transducers is less than one half wavelength at the highest frequency of interest.

6. An array according to claim 1, wherein said arraying means further comprises:

one of drive and receiving means for generating transducer drive signals and for receiving transduced signals therefrom, respectively; and

delay control means coupled with said acoustic transducers and with said one of said drive means and said receiving means, for controlling an acoustic beam formed by said array.

7. An array according to claim 6, wherein said delay control means comprises delay lines.

8. An array according to claim 6, further comprising a second plurality of said acoustic transducers; and

second arraying means for arraying said second plurality of acoustic transducers at the vertices of a second polyhedron to thereby form a second transducer array, and for locating said second transducer array concentric with said first transducer array.

9. An array according to claim 8, wherein said second polyhedron has a different number of faces than said first-named polyhedron.

10. An array according to claim 8, further comprising one of second drive means and second receiving means for generating transducer drive signals and for receiving transduced signals, respectively; and

second delay control means coupled with said with said acoustic transducers of said second transducer array and with said one of said second drive means and said second receiving means, for controlling an acoustic beam formed by said second transducer array.

11. An array according to claim 8, wherein said first-mentioned polyhedron is an icosahedron, and said second polyhedron is a dodecahedron.

12. An array according to claim 8, wherein the diameter of said second array is selected to provide an interelement spacing in the range of 1/3 to 2/3 wavelength.

13. An array according to claim 11, wherein:

said polyhedron associated with said first array is larger than said polyhedron associated with said second array, whereby said second array is contained within the volume of said first array; and wherein:

said drive means associated with said first array operates at a frequency lower than said second drive means associated with said second array.

14. An array according to claim 8, wherein said first-named polyhedron is one of an icosahedron and a dodecahedron, and said second polyhedron is the other one of an icosahedron and a dodecahedron.

15. A transducer array, comprising;

twelve acoustic transducers for use in a fluid medium, each of said transducers having maximum lateral dimensions less than one acoustic wavelength in said medium; and

arraying means for arraying said acoustic transducers at the vertices of one of an icosahedron and a dodecahedron.

16. A transducer array according to claim 15, wherein the intertransducer spacing in said array is in the range of 1/3 to 2/3 wavelength.

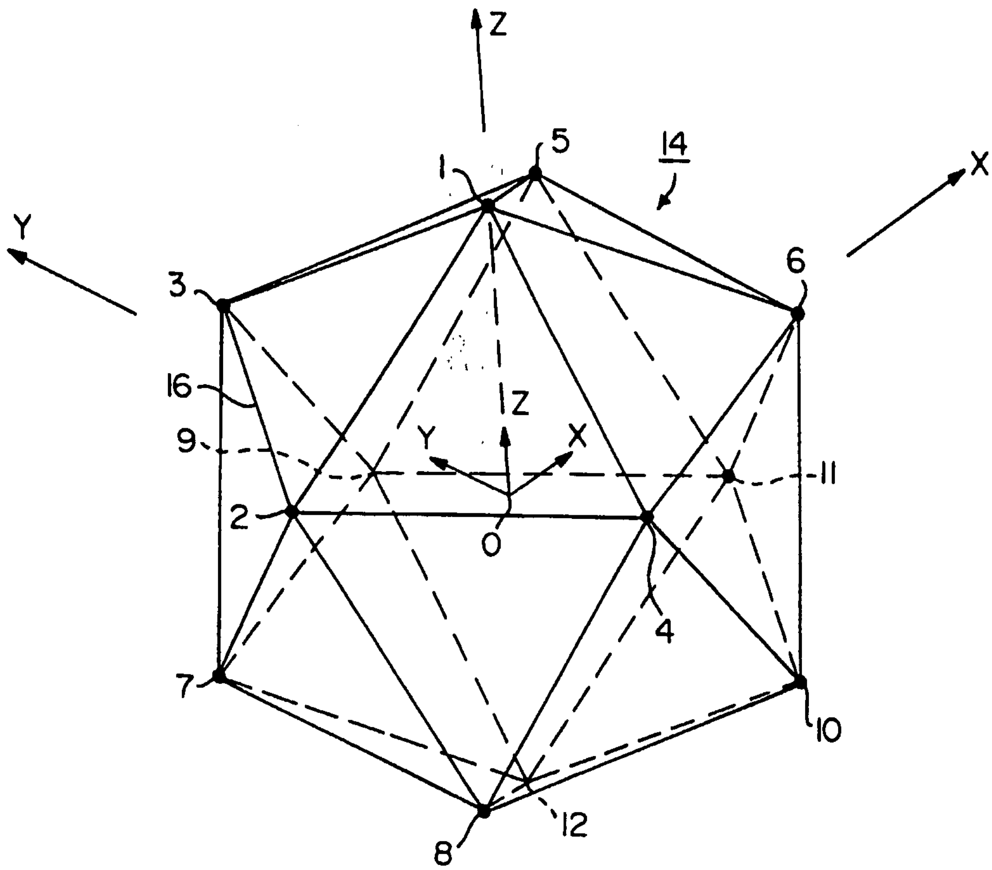


FIG. 1

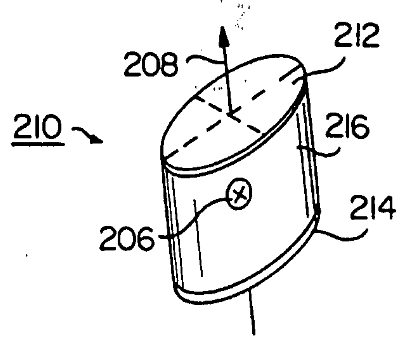
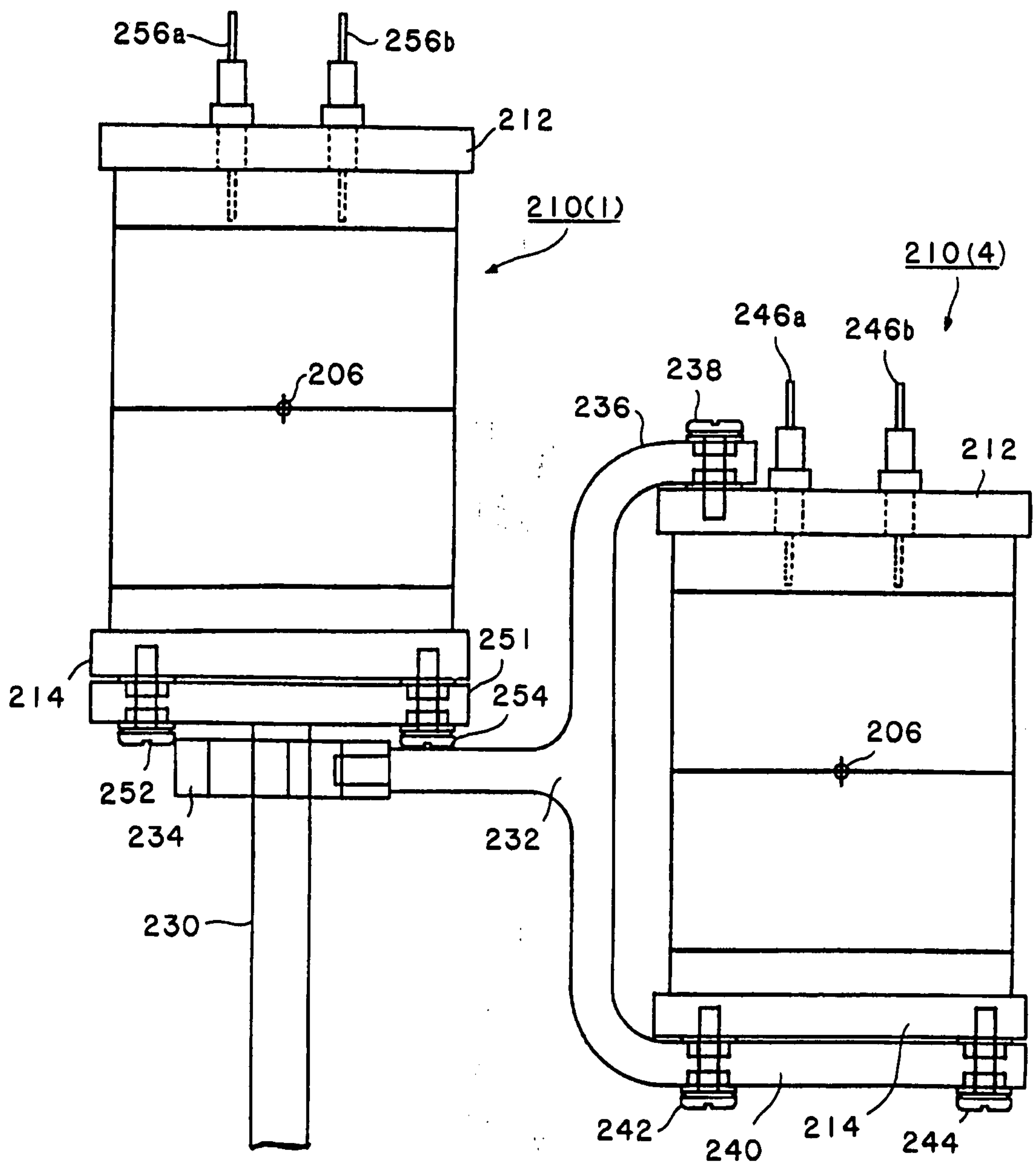


FIG. 2a



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256b
212
210(1)
210(4)
246a
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242
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214
244

FIG. 2b

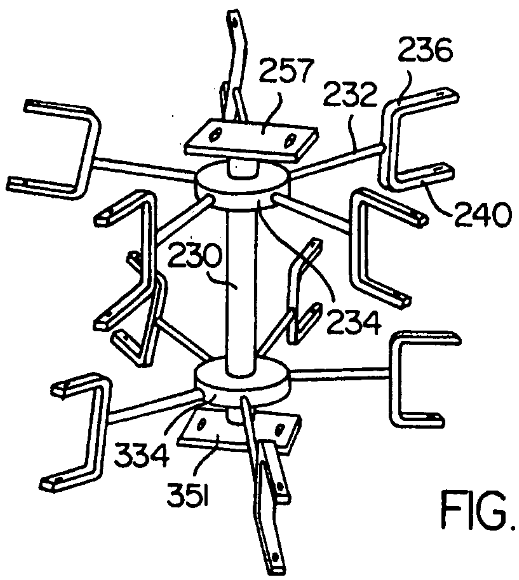


FIG. 3

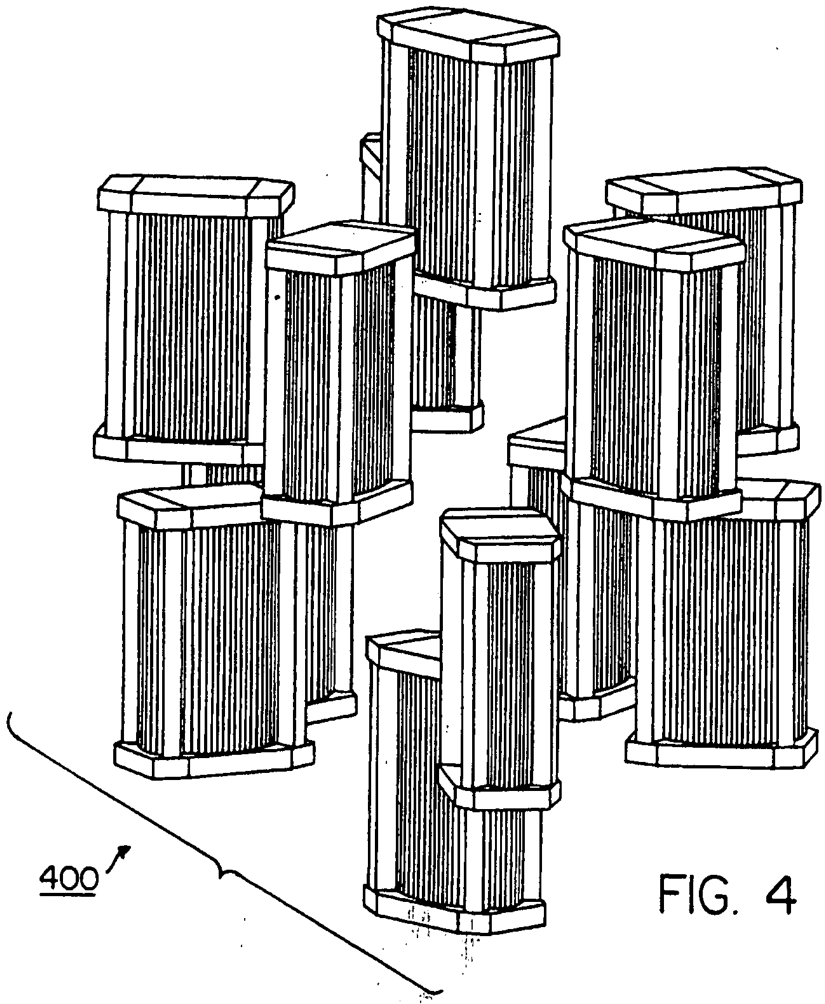
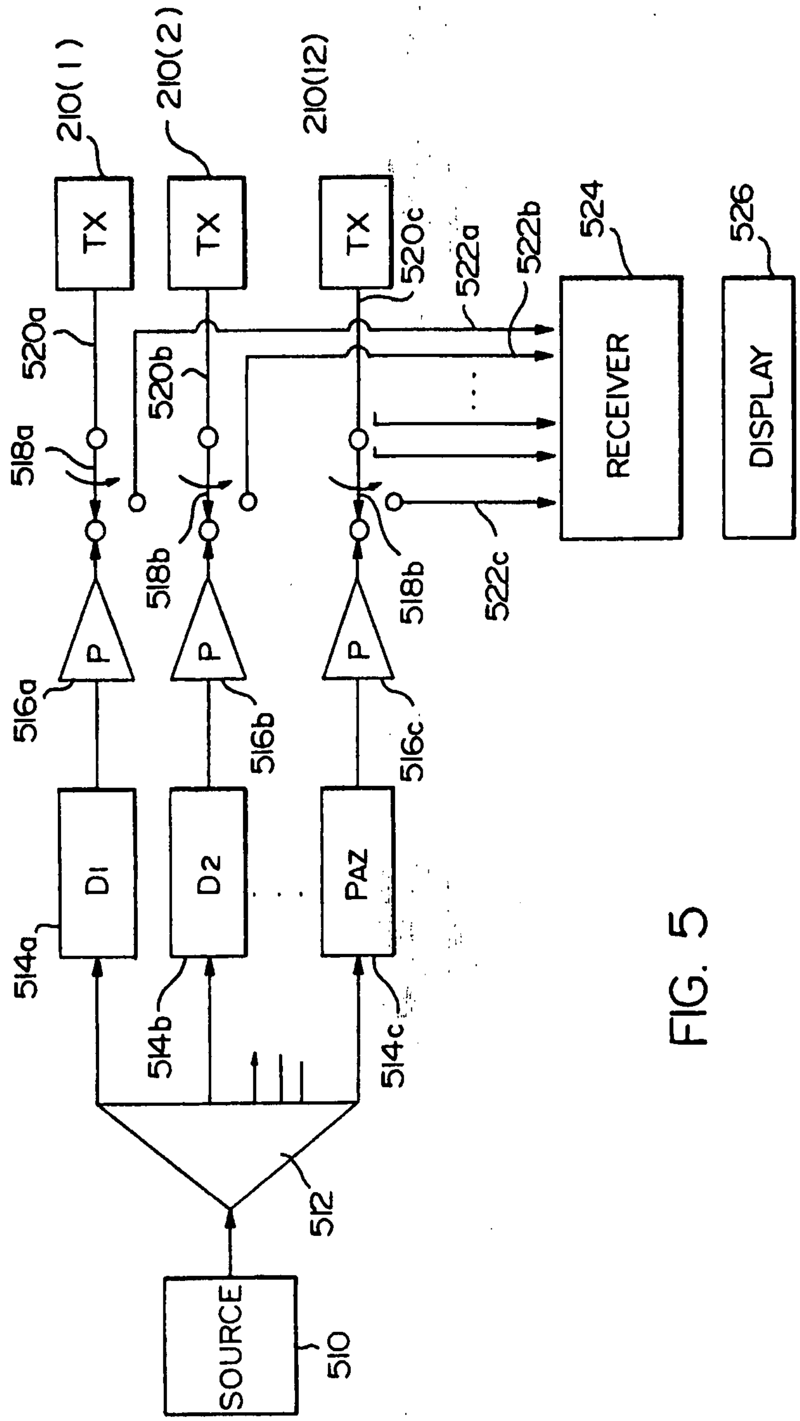


FIG. 4



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514b
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P
516a
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516c
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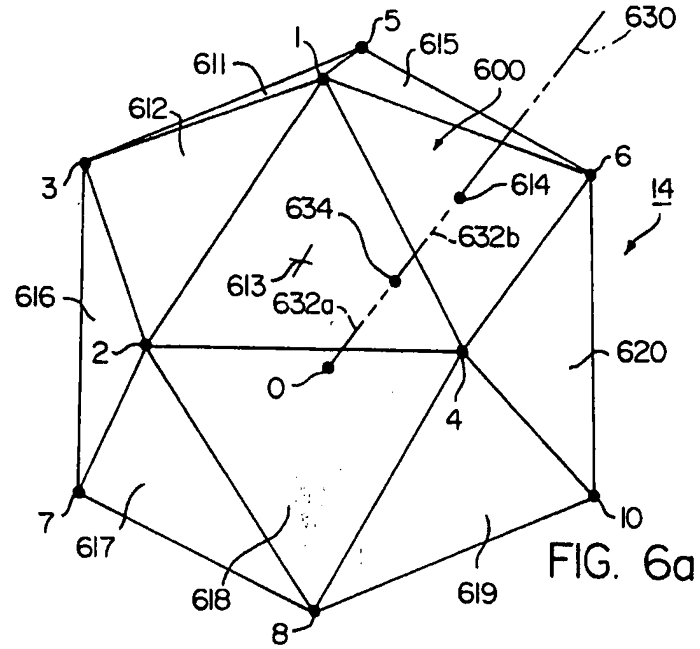
518b
TX
210(1)
210(2)
210(12)
520a
520b
520c
522a
522b
522c
RECEIVER
524
DISPLAY
526

FIG. 5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619
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FIG. 6a

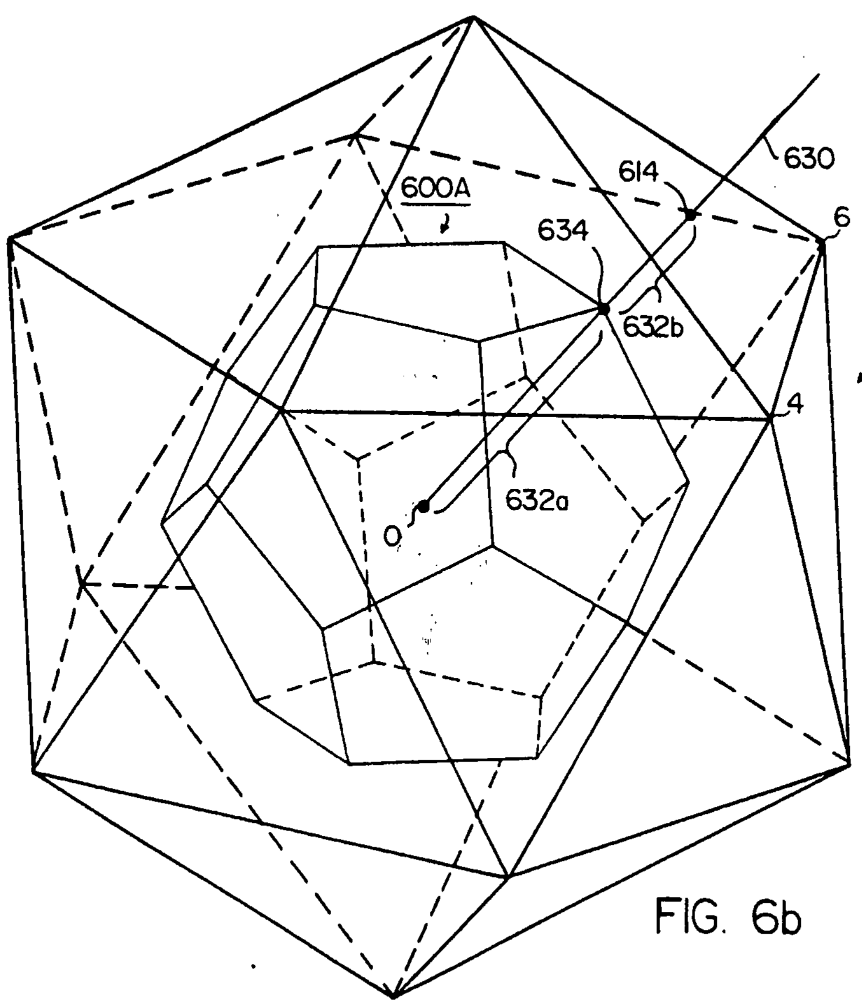
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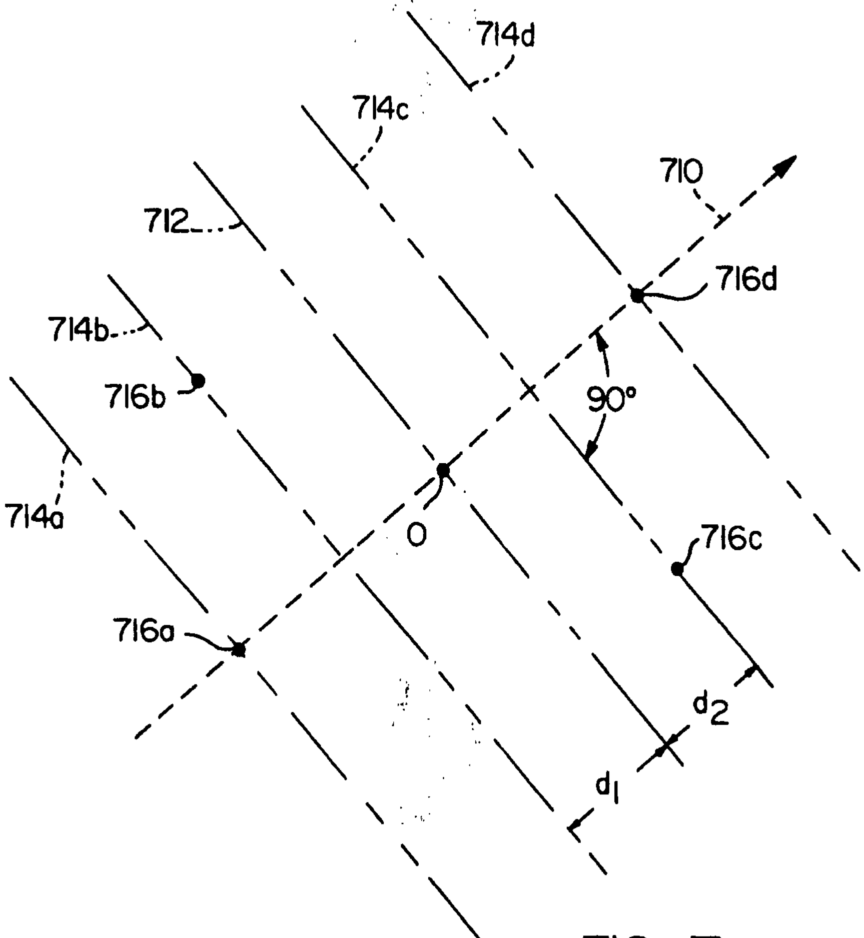
FIG. 6b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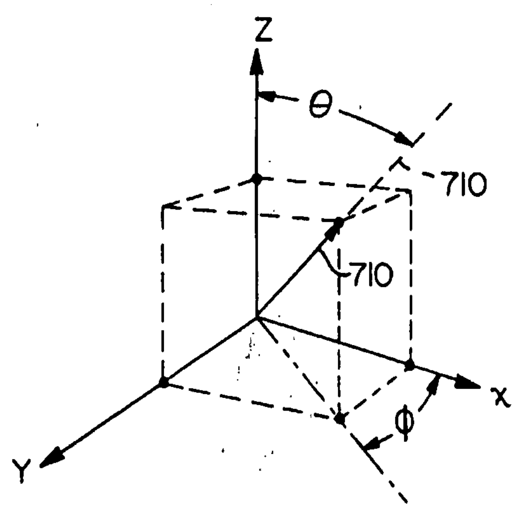
d_2
d_1

FIG. 7a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Y

FIG. 7b

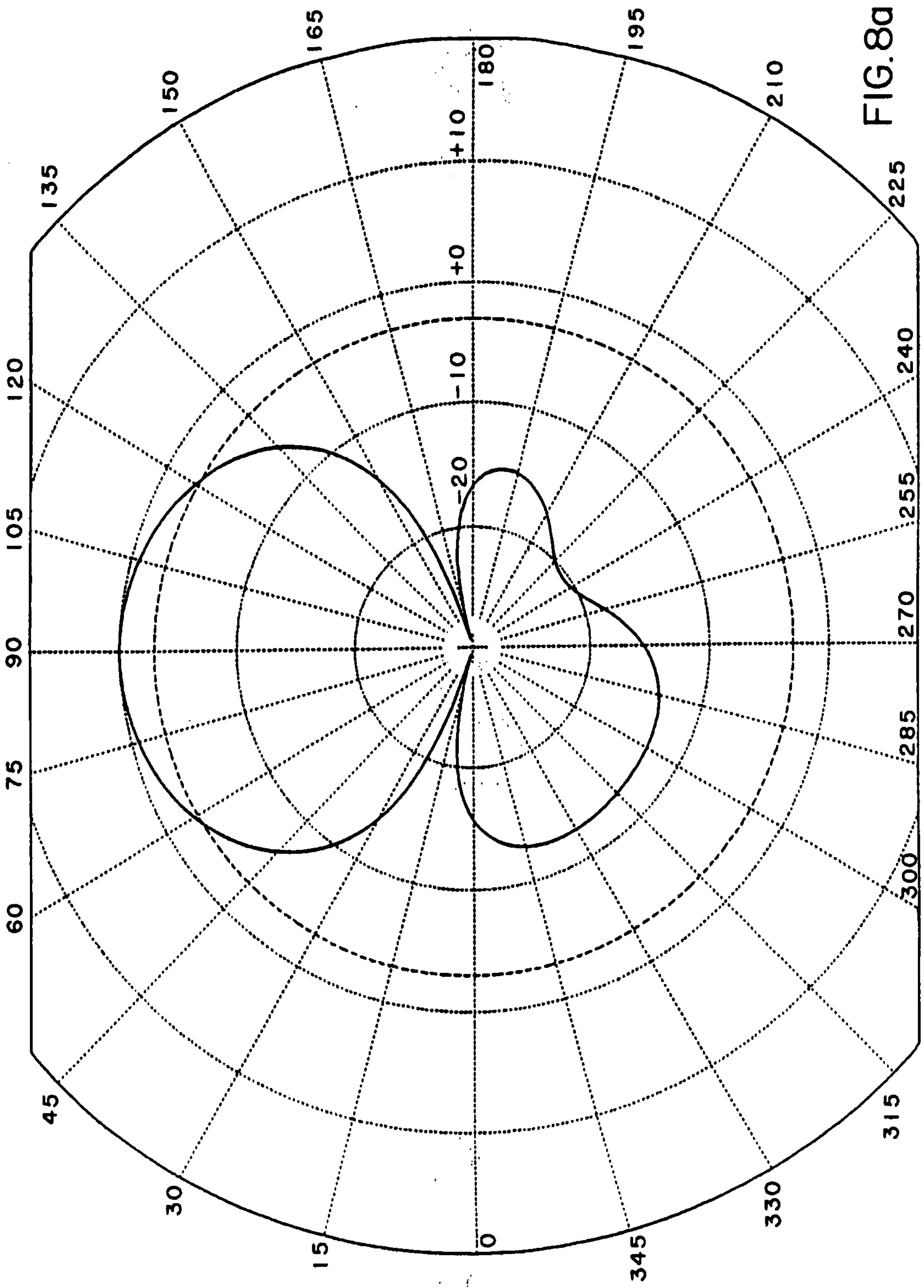
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FIG.8a

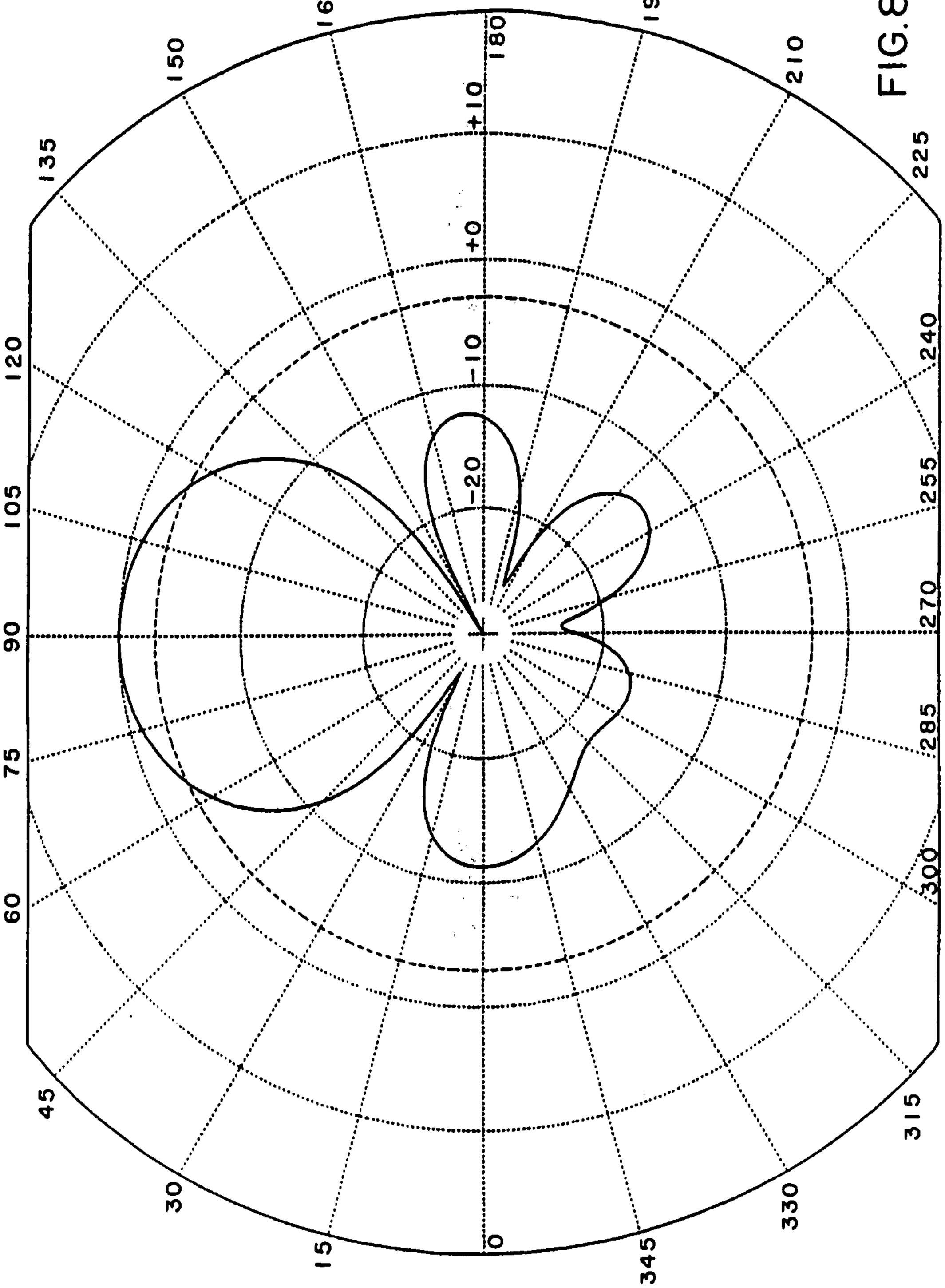

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FIG.8b

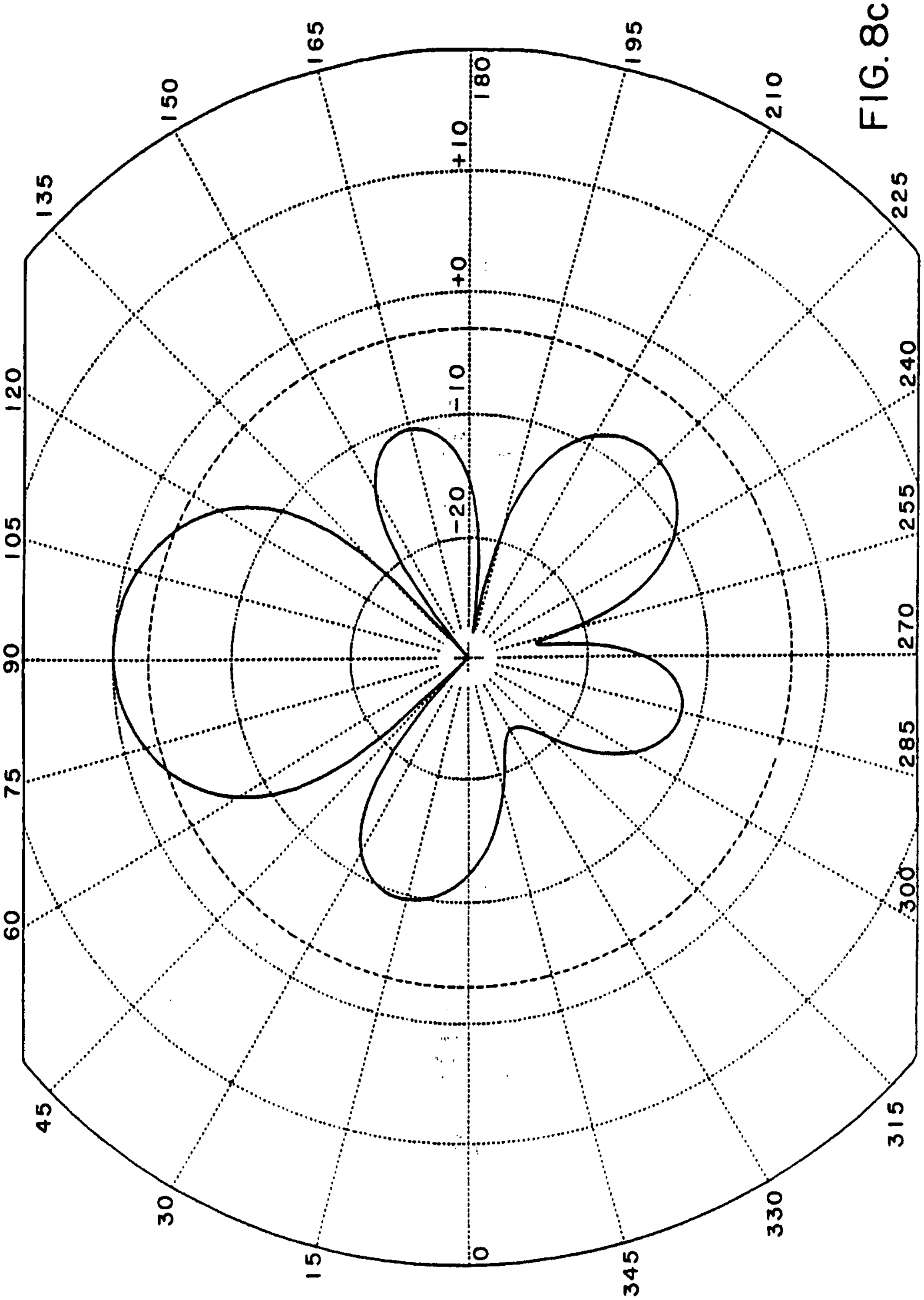
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FIG. 8c

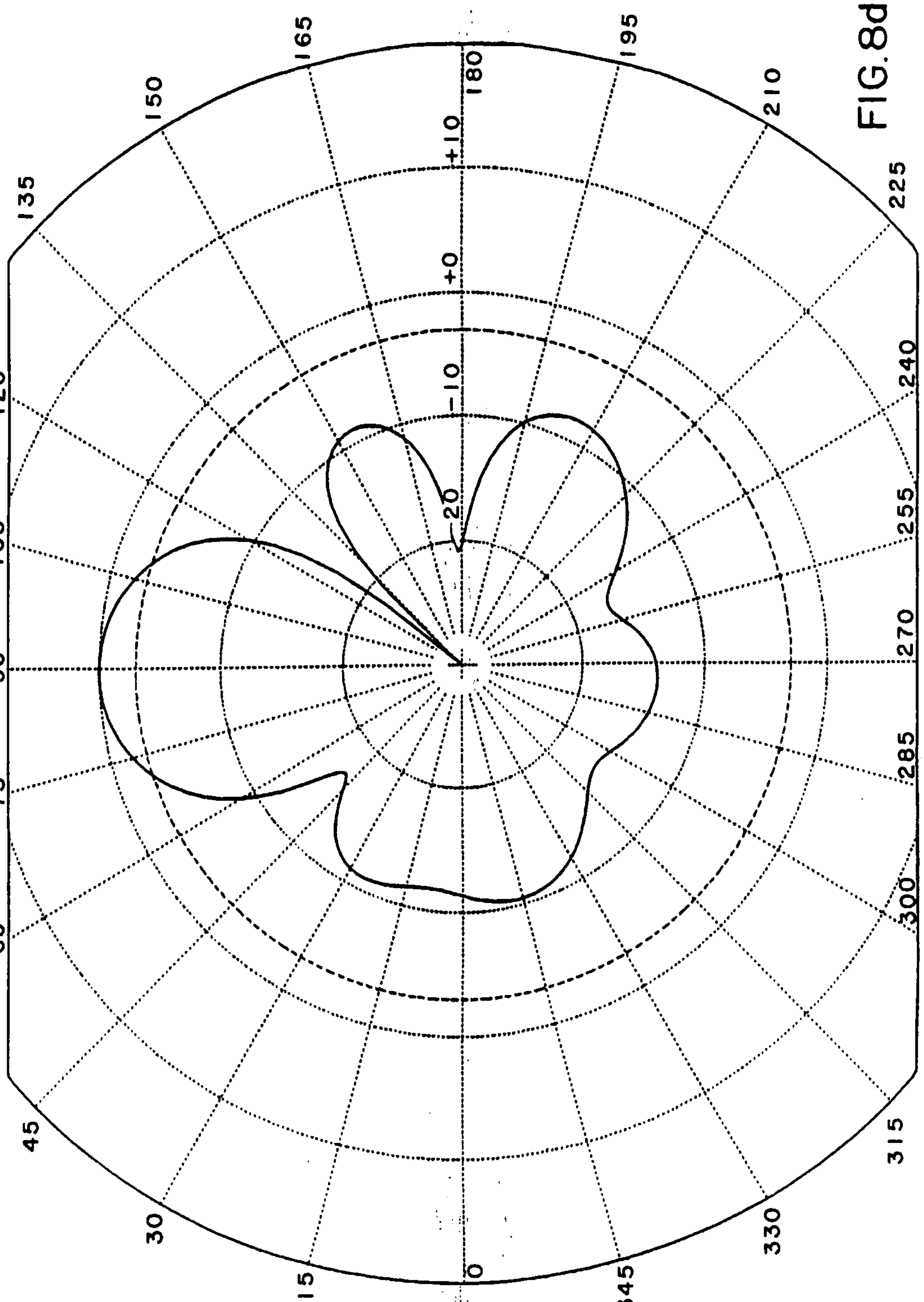
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FIG.8d

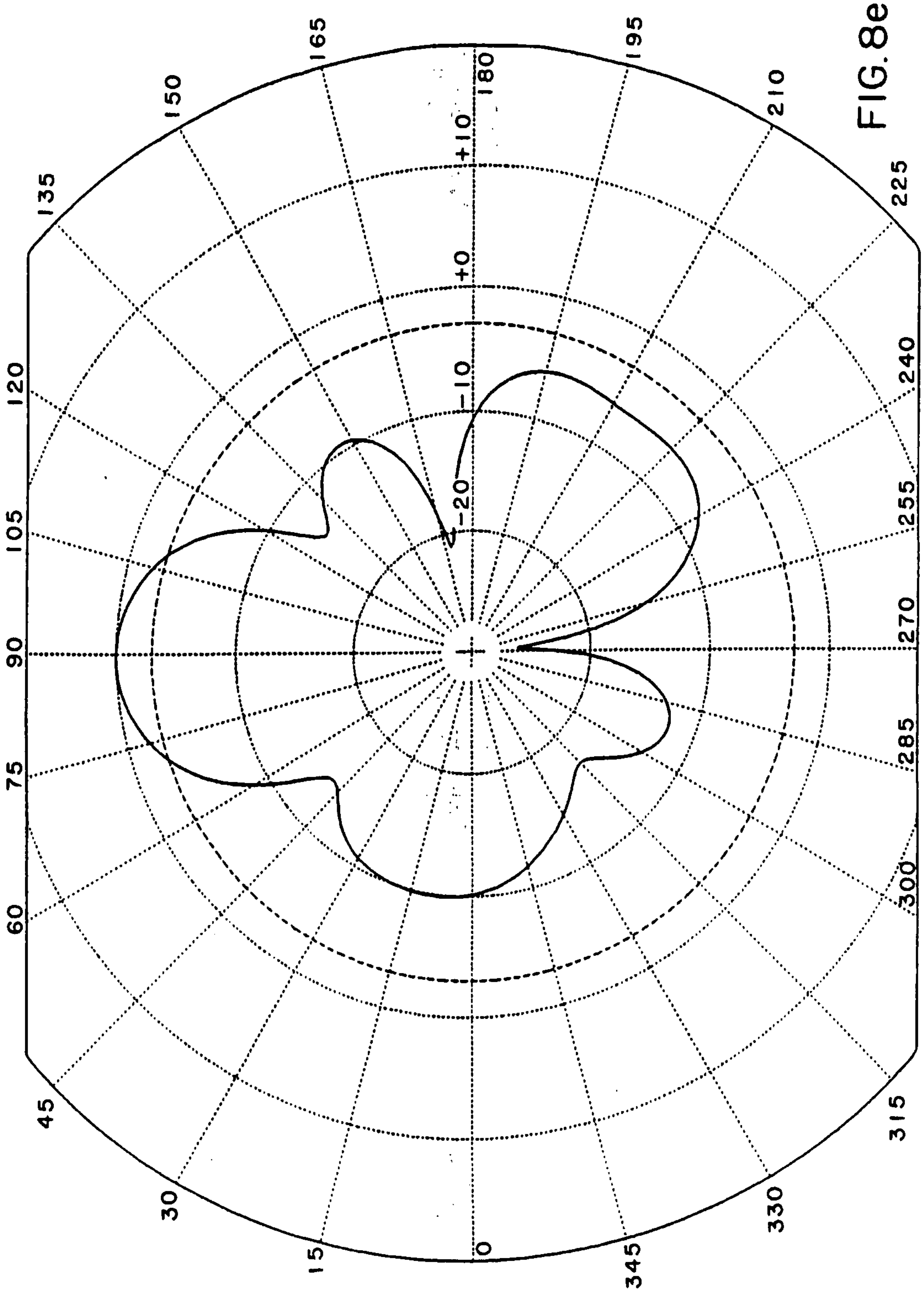

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FIG. 8e

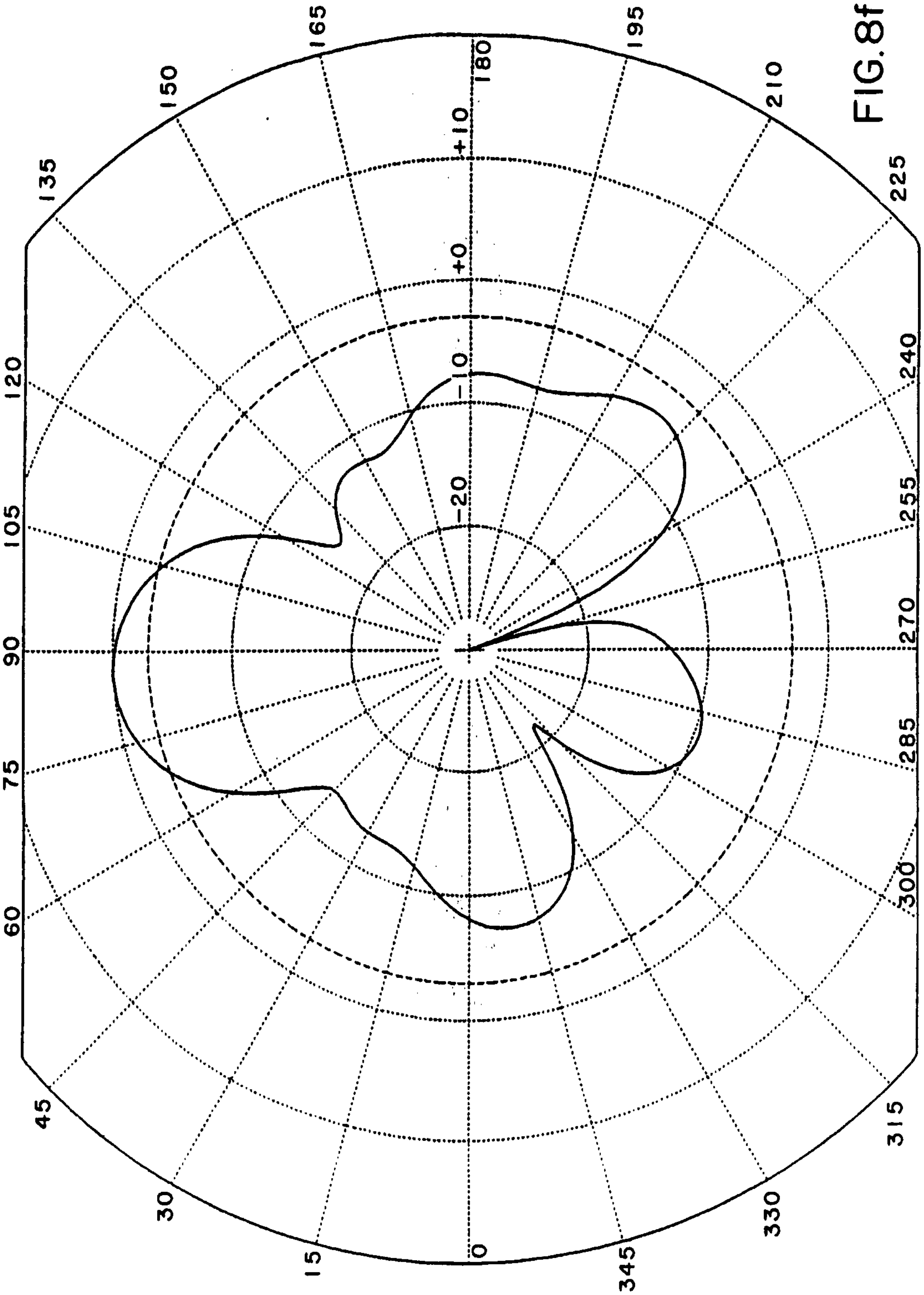

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FIG.8f

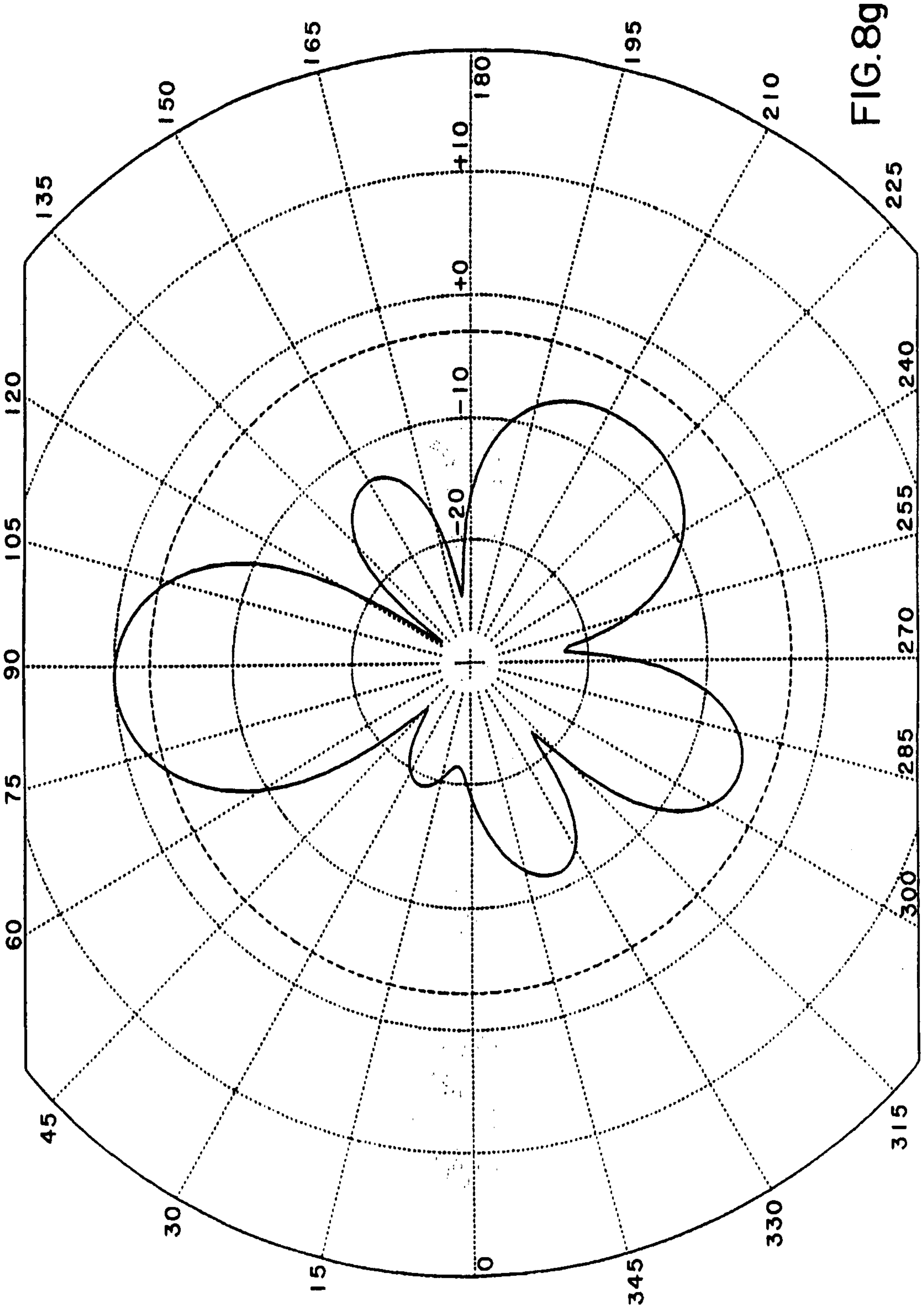
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FIG.8g

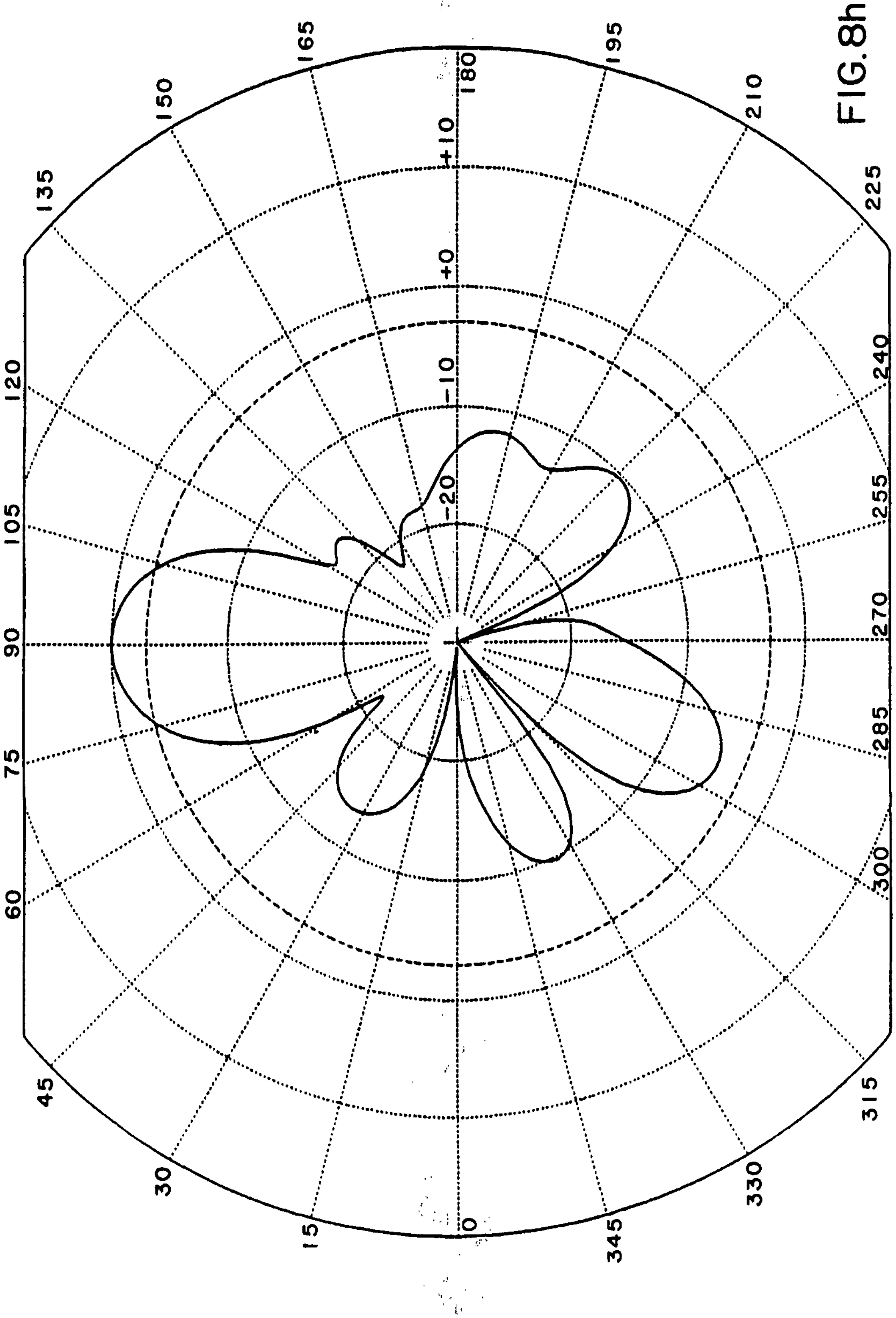
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FIG.8h

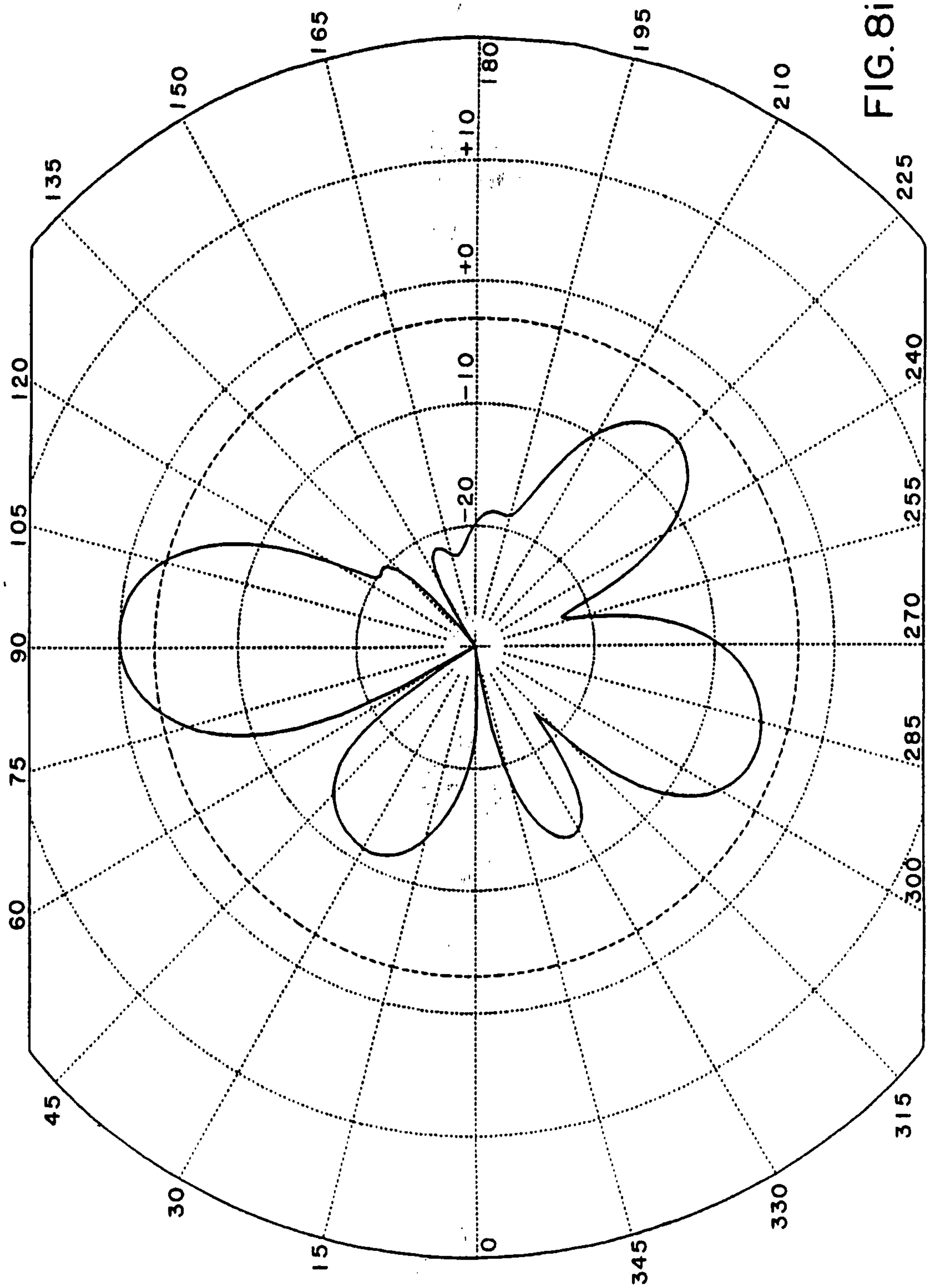
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FIG.8i

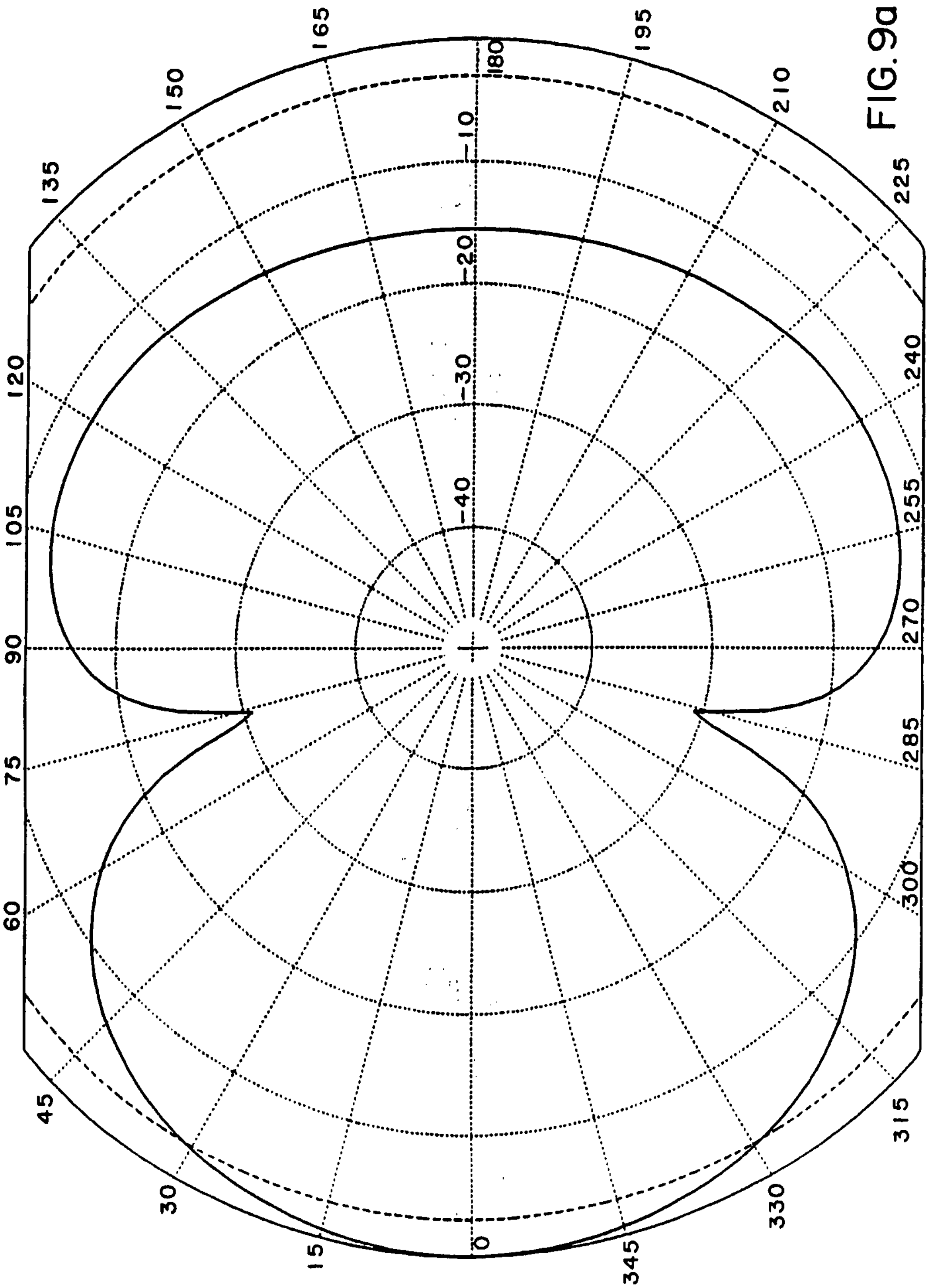
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FIG.9a

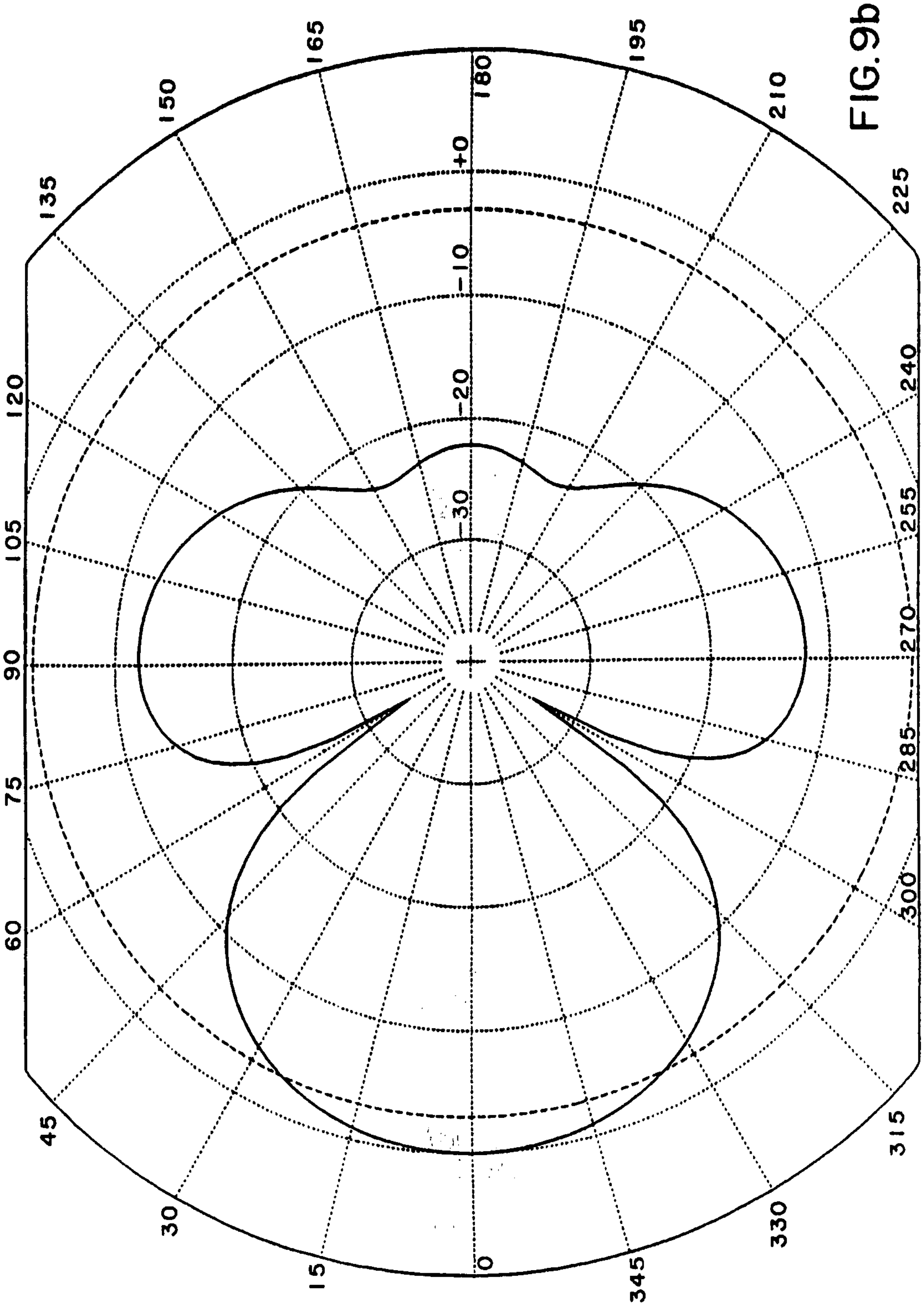
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FIG.9b

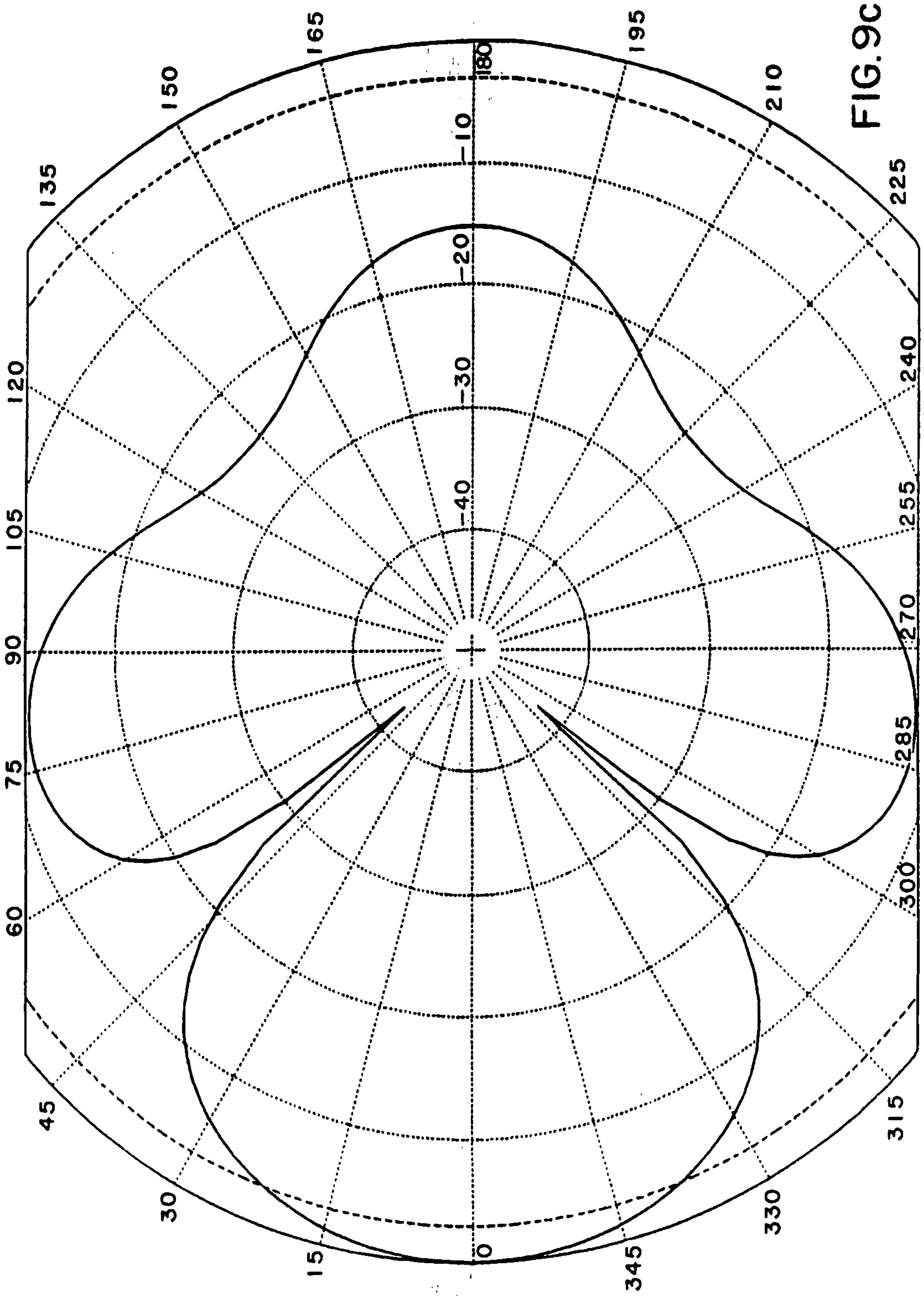

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FIG.9C

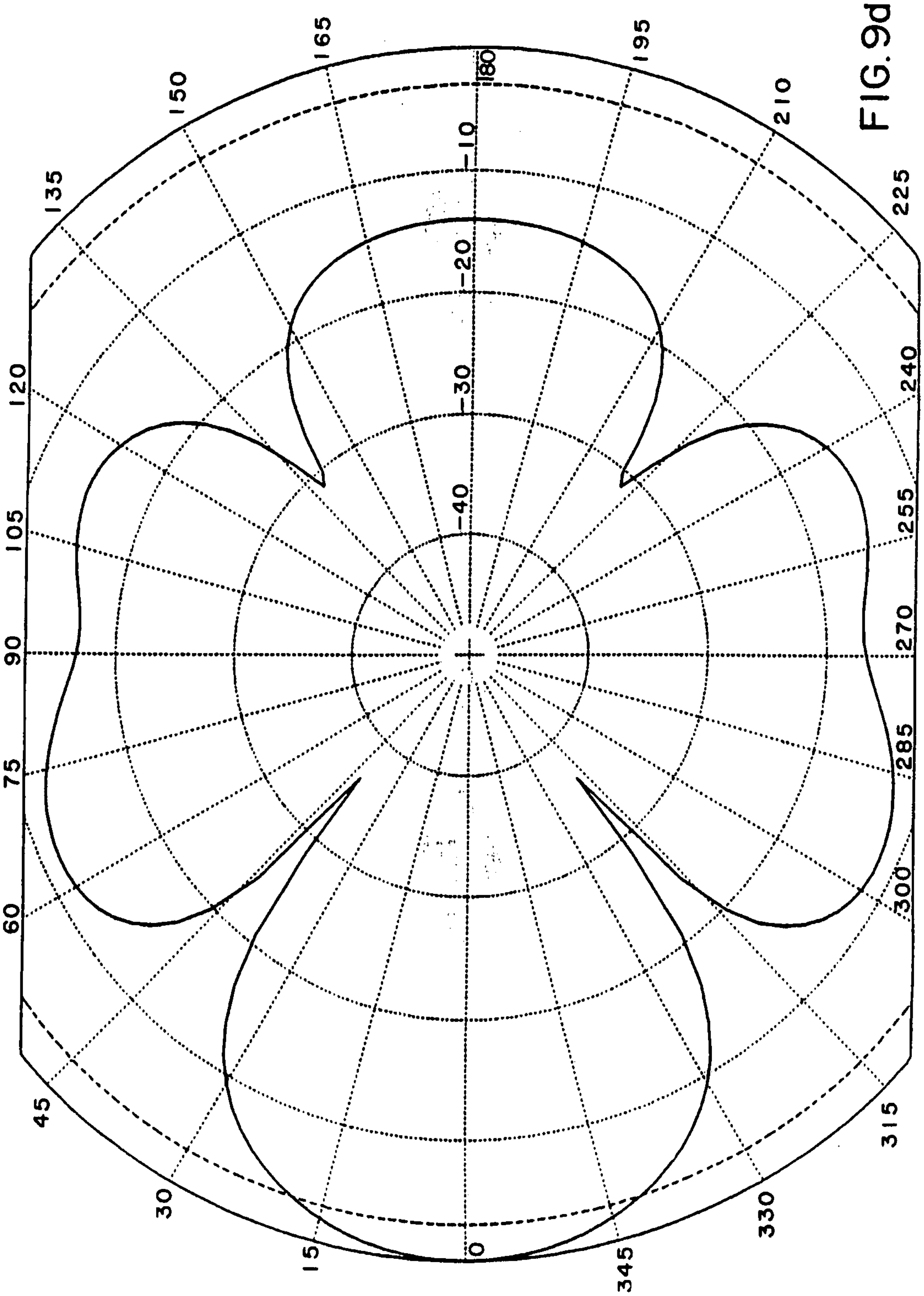
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FIG.9d

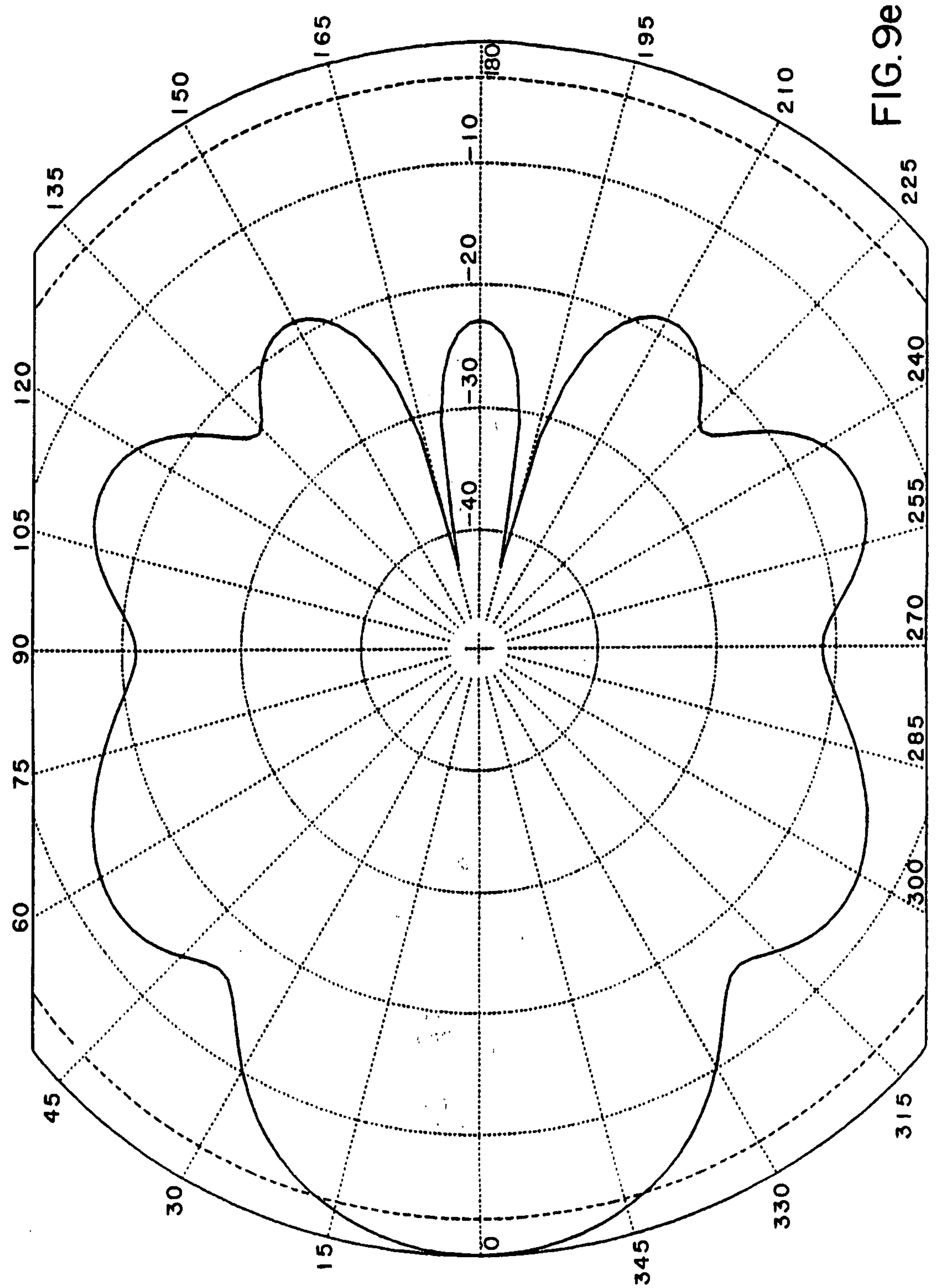
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FIG.9e

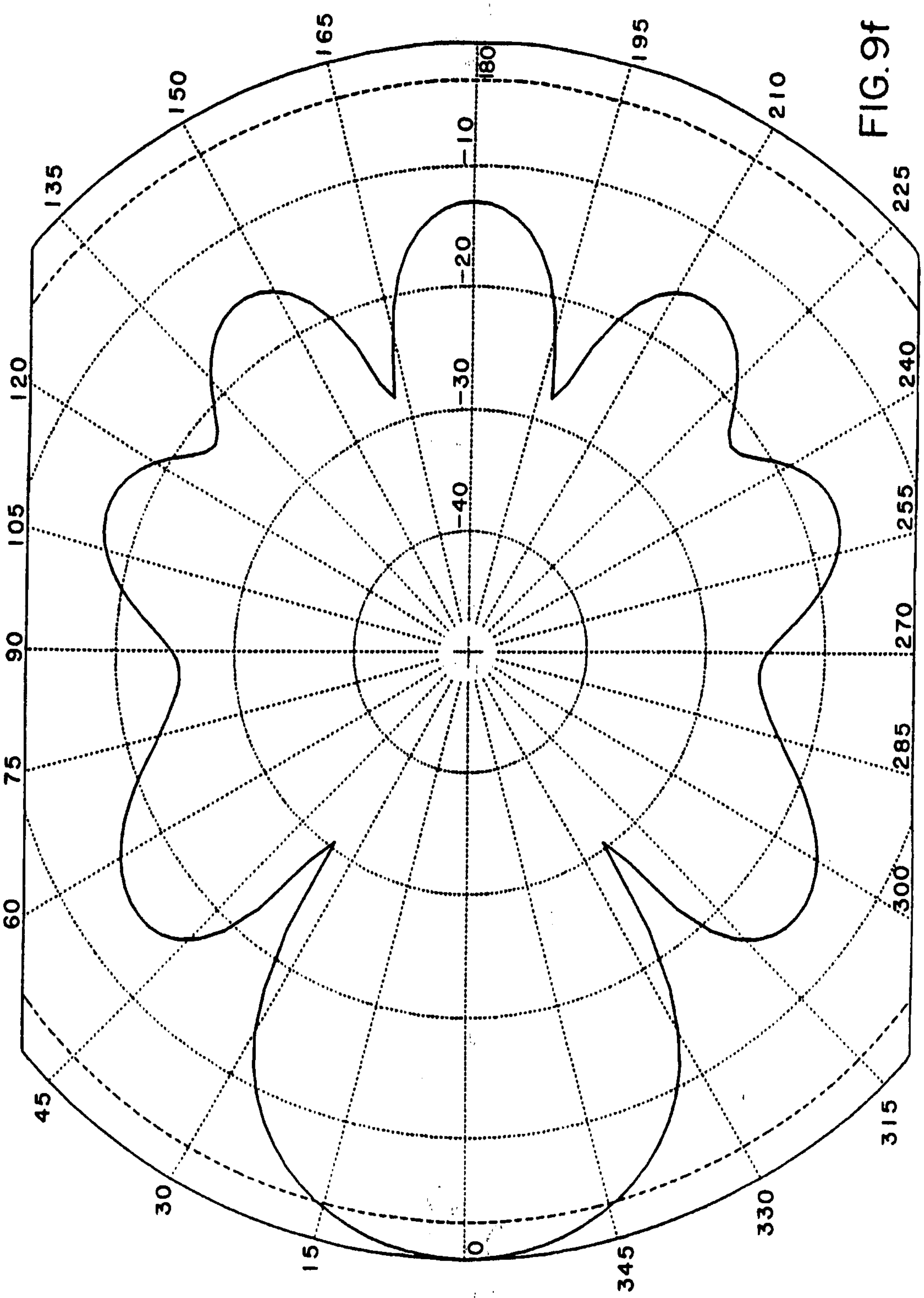
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FIG.9f

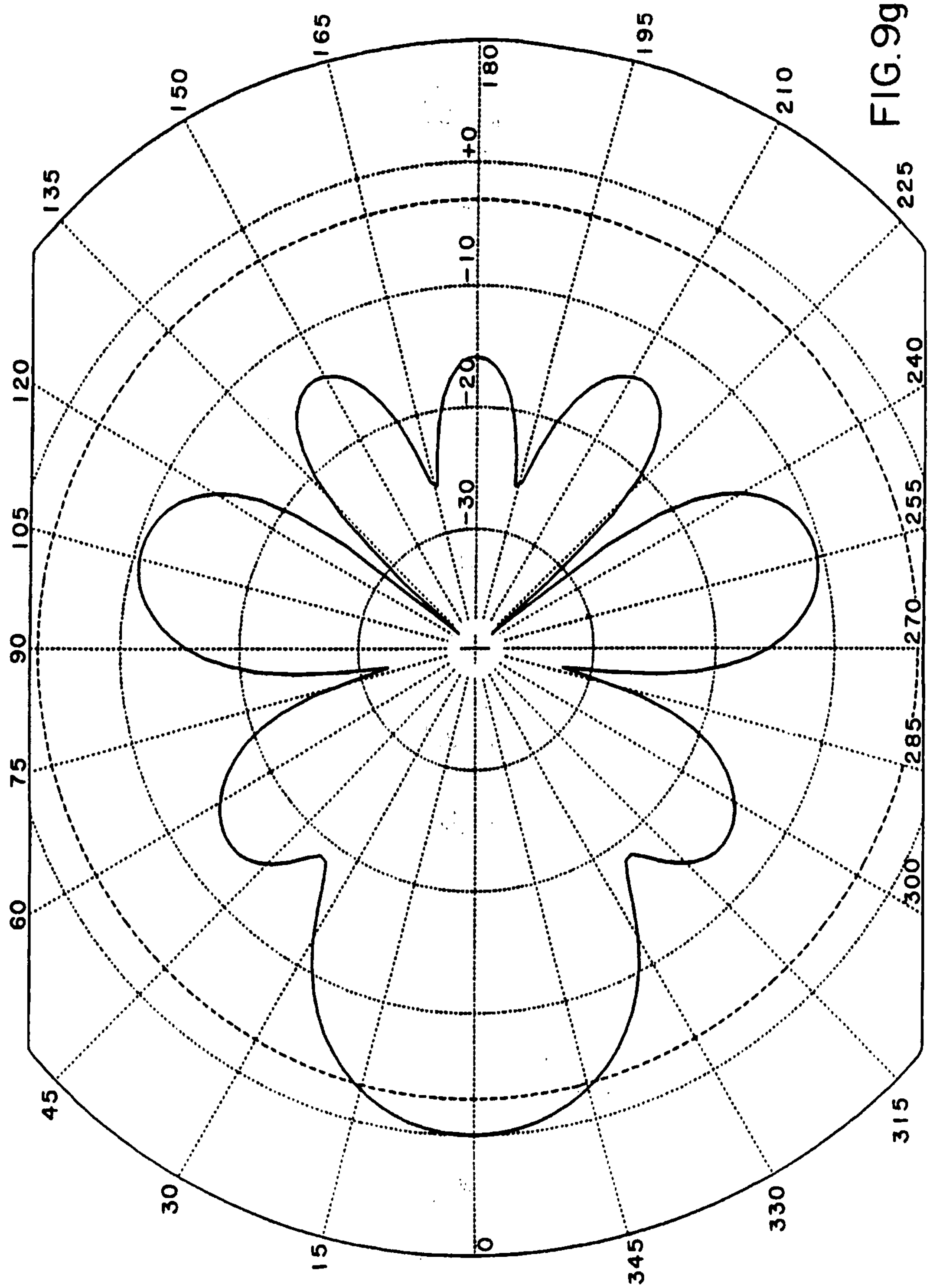

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FIG.9g

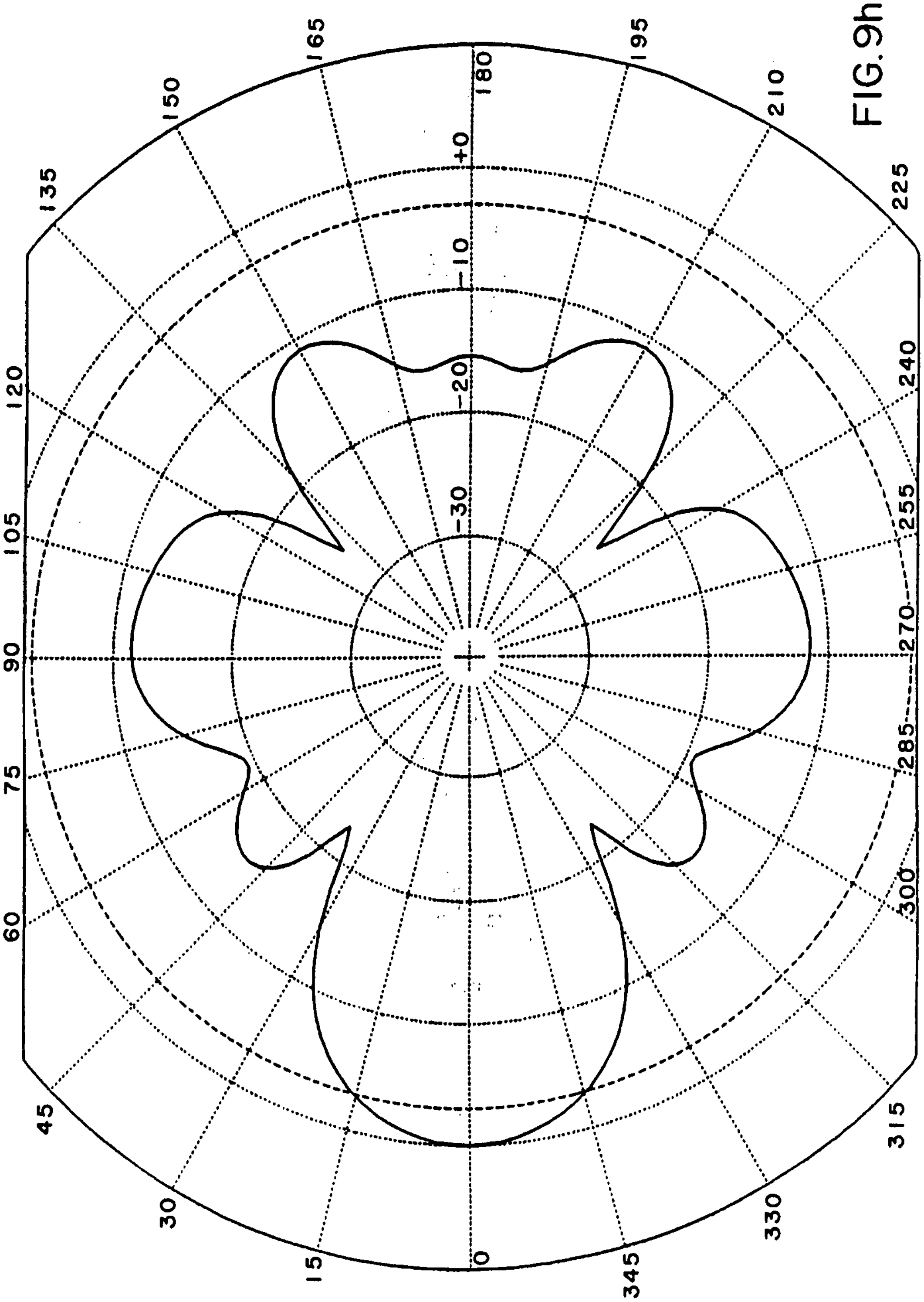
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FIG.9h

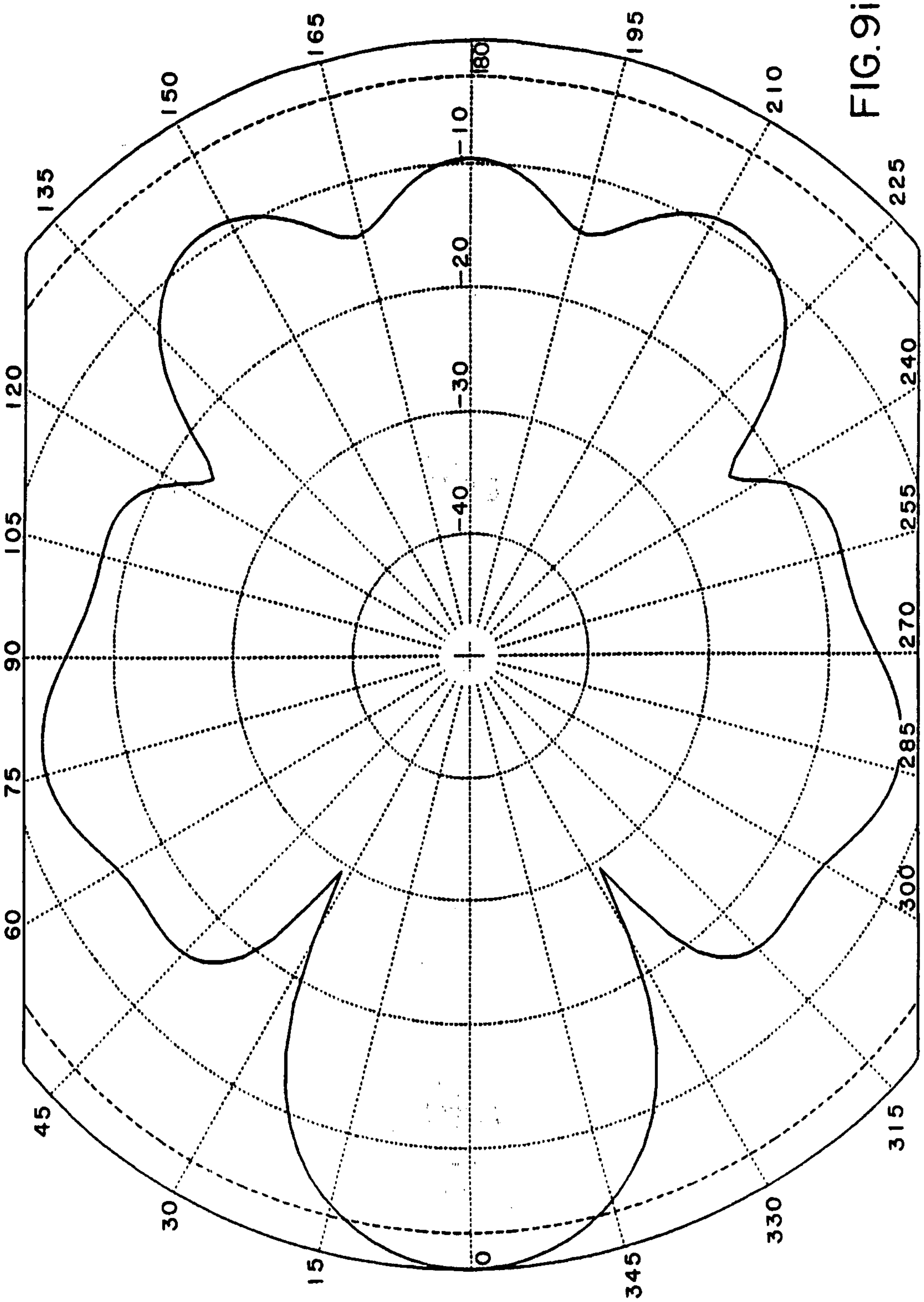
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FIG.9i

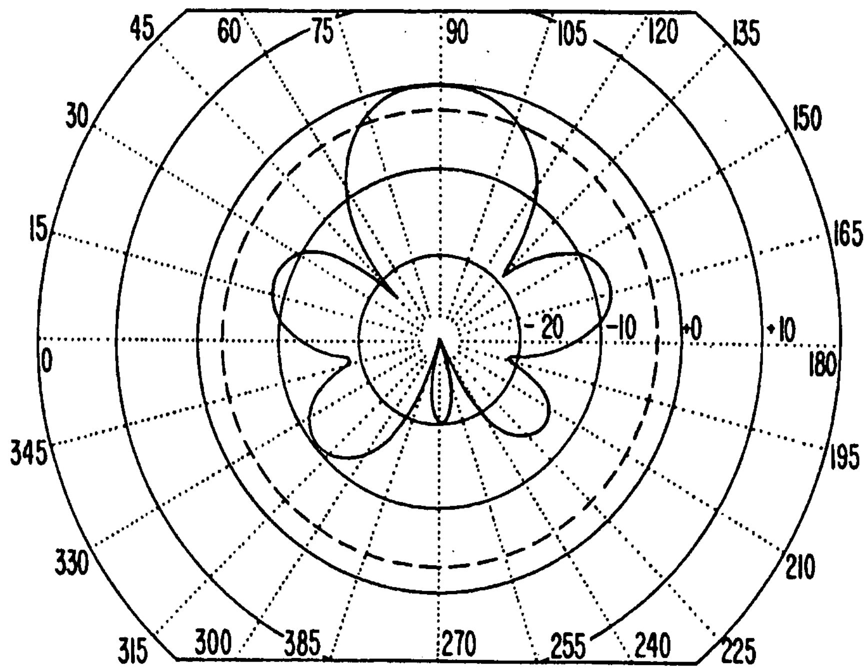

FIG. 10a

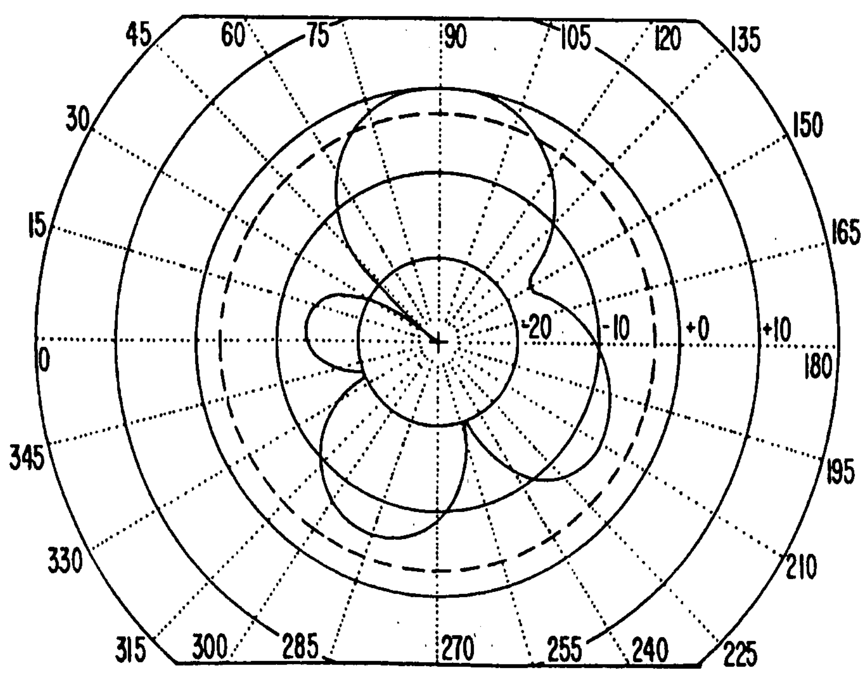

FIG. 10b

INTERNATIONAL SEARCH REPORT

Internal Application No
PCT/US 95/00910

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G10K11/00 H04R1/40 B06B1/02 B06B1/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G10K H04R B06B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US,A,4 673 057 (GLASSCO JOHN M) 16 June 1987	1-5,11,12
Y	see abstract; claim 1; figures 2,4-6	6,7
X	PATENT ABSTRACTS OF JAPAN vol. 009 no. 099 (E-311) ,27 April 1985 & JP,A,59 224998 (MITSUBISHI JUKOGYO KK) 17 December 1984, see abstract	1-5,15,16
Y	EP,A,0 333 552 (GEN ELECTRIC CGR) 20 September 1989 see column 5, line 33 - line 36; claims 1,3	6,7
A	FR,A,2 278 218 (NAT RES DEV) 6 February 1976	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 1995	14. 06. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	de Heering, P

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 95/00910

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A-4673057	16-06-87	NONE		
EP-A-0333552	20-09-89	FR-A-	2628539	15-09-89
		JP-A-	2007946	11-01-90
		US-A-	5027659	02-07-91
FR-A-2278218	06-02-76	GB-A-	1512514	01-06-78
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		JP-A-	51032319	18-03-76
		JP-B-	62016080	10-04-87
		NL-A-	7508270	14-01-76
		US-A-	4042779	16-08-77